GOLD MINING MACHINERY

W. H. TINNEY

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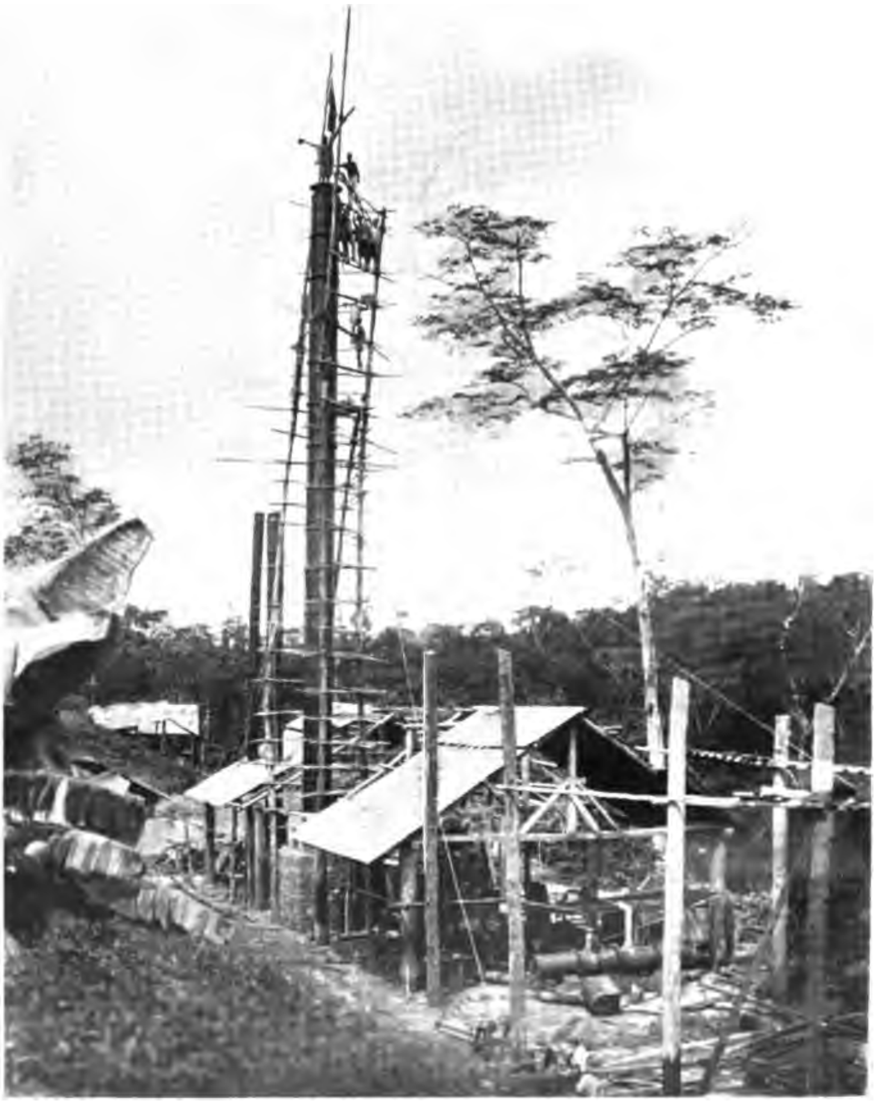

ERECTING 100-FT. SECTIONAL STEEL CHIMNEY BY BAMBOO SCAFFOLDING.

[*Frontispiece.*

GOLD MINING MACHINERY

ITS SELECTION, ARRANGEMENT, & INSTALLATION

A Practical Handbook

FOR THE USE OF MINE MANAGERS AND ENGINEERS

INCLUDING

PARTICULARS FOR THE PREPARATION OF SPECIFICATIONS AND ESTIMATES

BY

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MINING ENGINEER

FORMERLY IN CHARGE OF MACHINERY AT THE MYSORE GOLD MINE AND
MANAGER OF THE ABOSSO, AFFANTOO, TAQUAH AND ABOSSO, PRESTEA, AND OTHER GOLD MINES
MEMBER OF THE INSTITUTE OF MINING AND METALLURGY

With Numerous Illustrations

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PREFACE.

In the course of a somewhat extensive experience I have often needed the assistance of a manual describing the principal features of the Machines employed in Gold Mining—their sizes, capacities, and speeds—and the rules and formulæ governing their use.

These points (it is believed) will be found sufficiently embodied in this work, and—so far as I am aware—no other volume yet published covers the same ground.

Lengthy descriptions and catalogue extracts have been omitted, except in so far as the latter refer to the capacity of individual machines, while the notes on erection and other matters have been framed with the view of rendering practical assistance to the Manager and Mechanical Engineer.

PETWORTH,
NEWTON ABBOT,
August 1906.

CONTENTS.

APPENDIX OF MISCELLANEA.

LIST OF ILLUSTRATIONS.

GOLD MINING MACHINERY.

CHAPTER I.

INTRODUCTORY.

THE remarkable growth of the gold-mining industry in recent times—a fact of notable importance to mankind—is, to a great extent, attributable to the modern development and perfecting of the machinery employed. For on the efficiency of the plant and equipment of a gold-mine depend both the economical treatment of high-grade ores and the profitable handling of low-grade deposits. In the latter case, especially, it is of the utmost importance to utilise every possible mechanical advantage tending to reduction in expense of working and consequent economy in cost of output.

The design and general arrangement of mining plant are influenced by many considerations; the most important of these are the mode of deposition of the ore body and character of the ore, the power available, and the amount and quality of the fuel and water accessible. In addition to these main features, various matters of secondary importance must be regarded, such as the extent of space at disposal for arrangement of the plant, and the contour of the ground as affecting all means of transport within the property. The ability of the attendants controlling the plant forms another factor to be considered, involving the question whether the increased economy of highly complex mechanism would justify, in particular cases, the importation of a skilled staff.

When installing boilers of given evaporative power the inferiority of local fuel must not be forgotten, nor the decreased draught and smokestack efficiency common in tropical countries.

The design demands regard to those matters of detail which go far towards fitting each machine to the particular conditions of its employment; as, for instance, the use of studs in place of bolts in machinery intended to work underground. Such practice is allowable with rock drills,

which are easily sent to surface for repair; but when applied to pumps it has led to disasters, for which the design is unfortunately seldom blamed.

The difficulties of transport to outlying districts often demand serious consideration; to what extent shall facility in this direction be obtained at increased cost both in manufacture and erection, and with a less efficient result.

A sectionalised machine, when erected where it was made, may be as efficient as any other form; but it is not so at the end of a long and difficult journey, when rust and rough usage have destroyed the accurately machined surfaces, and parts and connections have possibly been lost on the way. In such cases considerable skill is necessary to construct even a workable machine from the damaged remnants.

All these local, and therefore constantly varying, requirements preclude the adoption of any standard design or system of arrangement.

Orders for machinery, although originating at the mine, are seldom accompanied by complete plans and specifications; usually only the principal features are indicated, and reference in some cases made to those local conditions on which the design of the plant so largely depends.

The manager, necessarily a man of many parts, is not always conversant with mechanical details, nor may he be able to spare the time for the investigations demanded. In such cases he cannot always rely on his mechanical staff, who are often practical men with little knowledge of theory, proportions, and strengths. Fortunately such orders are usually placed with manufacturers making a speciality of this class of work; and the result is something suitable for the duty to be performed, if not best adapted to the peculiar conditions of local service.

Given an equipment of suitable capacity and design, its efficiency and cost of maintenance depend on the staff at the mine, on whom devolve the selection of proper sites, the provision of foundations, the correct alignment of parts to each other, and of units into a complete installation.

Comparatively few mines are equipped at once for the output required, the machinery being generally erected in units at different times to keep pace with underground development; and when competent guidance is absent, the machinery becomes arranged in isolated groups and patches, with little regard to centralisation or the relation of units to the whole.

The laying out and disposition of the mine plant are subject to conditions as numerous and complex as the design; no rules can be laid down, though general principles may be indicated.

In addition to the work of installing new machinery, the mechanical staff is daily confronted with problems arising from the state of the plant: in one mine a thousand gallons per minute are pumped regularly and without difficulty, another may be unable to cope with the same quantity hourly. Only those who have experienced it know the strain and worry of attempting to get regular results with inefficient and worn-out machinery.

Pumps break down, boilers leak, and pipes burst at all hours of the night and day, while the rush of repair work is carried on by those too fully alive to the hopelessness of their task.

Just where they are most needed, the means for repair are frequently wanting, and no machine tools are to be found. On such mines even the screwing gear is incomplete, and some sort of a thread is made on a one-inch bolt by a pair of worn-out five eighths dies.

Yet, even under these conditions, good work is done; such difficulties call into play the fullest energy and resourcefulness of the staff. On one mine of this character the crank shaft of the mill engine broke twice in a fortnight, first through the pin, then through the web; yet it was repaired and the mill kept going for two months until a new shaft could be obtained; the repairs being carried out entirely by native labour, and a ratchet brace the only tool available.

As regards the running of machinery, there is little doubt that greater economic efficiency in the production and use of power would be obtained if the results were tabulated and made more apparent, and if the cost of a hundred horse-power spent in raising ore or water were known with the same accuracy as the gold extraction. The data required are easily obtainable, the calculations by no means involved; yet on many mines power is produced regardless of cost, efficiency untested and unknown, the indicator never used.

Take, for example, the case of an air compressor using more than its common supply of fuel; as most engines are provided neither with counter nor meter, it is not easy to decide whether increased work results from the greater consumption. Still more difficult is it, in case of loss of efficiency, to trace and locate the loss, which may be either in boilers, compressor, drills, or connections.

The interests at stake are high, and this need of efficiency often apparent in no small degree; yet it is only on a comparatively few well-established mines that inducements are offered to the right class of man to take charge of the plant.

Often the training rather than the man is at fault; any sort of training, marine or otherwise, being deemed sufficient; theory and practice are not combined, and even practice is limited to ordinary workshop experience.

Many mechanical engineers during the whole course of their training may have had nothing to do with foundations or pipe connections, or been taught how to lay off a line of shafting. In the wider sphere of outdoor work new phases arise; while in foreign countries the accustomed facilities may be non-existent, advice and assistance in emergencies unavailable.

Book knowledge cannot replace experience, supply resourcefulness, or provide for the many possible combinations that may arise. Still, the Author hopes this work may prove useful to those engaged in this im-

portant and ever-increasing industry; that it may assist managers in the selection of suitable equipment and indicate the principles on which the various parts are assembled in correct relation to each other; while to the mine engineer it may afford some of that information which workshop routine fails to impart.

CHAPTER II.

MOTIVE POWER.

Combustion—Fuels and their Value—Steam—Superheated Steam—Heat Losses—Steam Motors—Water Power—Gauging Supply—Horse-power Available—Forebays—Ditches—Flumes, Pipes—Water Wheels—Turbines, Penstocks—Single and Double Vortex Turbines—Pelton Wheels—The Action of Gas, Oil and Petrol Motors—Electricity—Action of Dynamos—Fixing and Running Dynamos and Motors.

Steam.

Combustion.—As most of the power used in gold-mining is obtained from steam, it will be advisable to consider briefly the principles of combustion and steam production, especially as in most works of reference those features directly affecting the result are often obscured in masses of more detailed information. Even in the boiling of water an acquaintance with the theory of the subject is essential if our efforts are to be properly directed.

Combustion is neither more nor less than oxidation, the chemical union of other elements with oxygen. This union takes place at varying rates; the extreme on the one hand being the explosion in the gas, oil, petrol motor, or gun; while as instancing tardy action we have the rusting of iron and the drying of paint.

In producing heat for power purposes, combustion proceeds at a medium pace and the oxygen is caused to combine with fuels which are valuable as heat producers in proportion to the hydrogen and carbon they contain. Hydrogen is three to four times as powerful an agent as carbon, hence the value of hydro-carbons, or mineral oils, as heat producers.

The atmosphere supplies the oxygen, and combustion commences when the elements are sufficiently heated for the chemical union to begin. In this union three parts by weight of carbon combine with eight by weight of oxygen, and form carbon dioxide; while one part of hydrogen combines with eight of oxygen and ultimately forms water.

No matter at what rate the combustion goes on, these proportions are rigidly adhered to; should there be a surplus of any one element it does not destroy or impair the combination, but passes away uncombined. Combustion, therefore, may be incomplete but cannot be imperfect. In perfect combustion of perfect fuel nothing is uncombined, nothing left—a result nearly attained in oil burners.

The quantity of air required depends on the carbon and hydrogen in the fuel. In the case of ordinary coal 12 lbs. of air contain the necessary oxygen, but in practice two, or even three times this amount is admitted to the furnace. The quantity varies also with the rate of combustion, a fierce fire and strong draught requiring less air than is necessary for slower combustion. The total heat obtained is the same in each case, though more may be available from the slow or fierce fire according to the temperature required.

In well designed plants not less than 20 lbs. or 260 cub. ft. of air will be required for each lb. of coal consumed, while more must be supplied if gas or oil is burned.

For the purpose of steam production the fuel is spread over a grate to offer a large area to the air admitted between the firebars. The quantity of fuel which may be burned on each square foot of grate surface depends on the quality of the fuel and amount of oxygen supplied, in other words the draught.

The following table gives the average coal consumption in lbs. of coal per hour per square foot of grate :—

Type of Boiler.	Draught.	Coal.	Fuel in lbs. per sq. ft.
Cornish	Ordinary .	Welsh . .	5
Cornish	Good . .	Welsh . .	10
Tubular and water-tube . .	½-in. pressure .	Welsh . .	20
Tubular and water-tube . .	¾-in. pressure .	Welsh . .	25
Tubular and water-tube . .	1-in. pressure .	Welsh . .	30
Tubular and water-tube . .	1-in. pressure .	South African	20
Locomotive	Steam blast .	Welsh . .	100

The evaporative value of fuel is measured in British thermal units, the unit being the amount of heat required to raise 1 lb. of water one degree in temperature, from 32° to 33° Fahr. A million such units are capable of evaporating 1035.2 lbs. of water from a temperature of 212°. The calorific value is highest in those fuels containing a large percentage of hydrogen, such as the hydro-carbons; 1 lb. of petroleum being equal to nearly 2 lbs. of coal.

The value of the fuels in ordinary use is as follows :—

Fuel.	British Thermal Units per lb.	Lbs. of Water at 212° Fahr. evaporated per lb. of Fuel.
Petroleum	27,000	28
Crude oil	20,000	21
Carbon, pure . . .	14,500	15.7
Coal	14,500	15
Wood	8,000	8

Although 1 lb. of good coal is capable of evaporating 15 lbs. of water, in practice this is never attained, the highest under careful test being 12.9 lbs.; in the everyday work of ordinary mine plant from 5 to 7 lbs. would be the average.

Each 30 lbs. of water evaporated into steam at 70 lbs. pressure constitute one boiler horse-power; therefore when 15 lbs. of coal are consumed per hour on each square foot of grate, and each lb. of fuel evaporates 7 lbs. of water, 3½ H.P. is being produced per square foot of grate.

But the total heat evolved in combustion is never available for power purposes, some being lost by radiation, some by incomplete combustion and in forming draught. Whether the draught be produced by fans, steam jet, or chimney, in neither case is it obtained without expenditure of power. If an ordinary chimney is used, the best temperature for the escaping gases at the top is 600° Fahr., or approximately 20 per cent. of the total power produced is expended in obtaining draught.

On account of the foregoing reasons only about 60 per cent. of the total heat obtained from the fuel is transferred to the water. In carefully designed plants it may amount to 75 per cent., and to 80 or even 85 per cent. when economy has been especially studied and feed heaters and superheaters provided.

The duty of the boiler is to transmit heat to the water within. This transmission is effected more quickly through thin walls than through thick, hence the quick steaming of those boilers whose tubes are thin and small in diameter. Heat is transmitted to the water in actual contact with the fire tubes, but water itself is a poor conductor and does not readily disseminate the heat it receives; thus the heating of the contents of the boiler is effected largely by circulation, or movement of heated water upwards and colder water downwards. Boilers with slow circulation are slow heat transmitters and slow steam producers.

A boiler evaporating 9¾ lbs. of water per lb. of coal is utilising about 75 per cent. of the heat produced, while many triple-expansion engines yield an indicated horse-power on from 12 to 20 lbs. of evaporated water per hour.

Steam is defined as "an elastic invisible gas, generated from water by the application of heat." Water at sea level boils at 212° Fahr., and cannot be made hotter in an open vessel at that level; in a closed vessel, however, the temperature of the water varies with the steam pressure. There is a great difference between the heat required to boil water and that necessary to turn it into steam, no less than 966° Fahr. being used in the change of form which the water undergoes, this amount being known as the latent heat of steam. But for this fact the change would be instantaneous and the whole of the water pass away as steam directly boiling point was reached; this is not the case, the change is gradual, and in accordance with the heat added. The heat required to evaporate 1 lb. of water is sufficient to melt 13 lbs. of gold.

The following table gives the temperature of ordinary saturated steam at different pressures, fractions being neglected:—

Gauge Pressure in lbs.	Temperature in degrees Fahr.	Weight of cub. ft. in lbs.	Cub. ft. in 1 lb.
10	240	.06199	16.13
20	259	.08508	11.75
30	274	.1077	9.285
40	286	.1299	7.698
50	298	.1519	6.583
60	307	.1736	5.76
70	316	.1951	5.126
80	323	.2165	4.619
90	331	.2378	4.205
100	338	.2589	3.862
125	353	.3113	3.212
145	363	.3532	2.833
175	377	.4153	2.408
210	392	.4876	2.051
310	424	.696	1.437

In this table it will be noticed that when the pressure is already high less heat is required to produce a given increase in pressure. Steam at an absolute pressure of 50 lbs. per sq. inch requires an additional 46° of heat to raise its pressure to 100 lbs., while 13° are sufficient to raise the pressure from 350 to 400 lbs., and 21° to raise steam of 400 lbs. pressure to 500 lbs. In other words, it takes 1,154 B.T.U. of heat to produce 1 lb. of steam at 90 lbs. pressure from water at 80°; an additional 15 B.T.U. doubles the pressure, hence one source of economy in using high pressure steam.

Ordinary, or saturated, steam contains from 5 to 15 per cent. of water, and, while in contact with the water in the boiler, cannot be heated above the temperature due to its pressure.

In separate receptacles this can be done. The superheater used for the purpose is a coil or nest of tubes through which the steam passes and around which the flue gases play. Being in communication with both engine and boiler the pressure is not increased. It is an advantage peculiar to superheating that increased heat and possible useful work are obtained without any increase in the steam pressure. Since the work done is represented by the difference in temperature between the steam admitted and that exhausted from the engine, greater range of heat gives greater useful work, or more work for the same fuel.

The use of superheated steam necessitates no special engines, gear, or alterations to existing motors; the advantages being most apparent in ordinary slide valve engines, pumps, and auxiliaries. Owing to the greater heat the density of the steam is diminished and the back pressure decreased, while there is less condensation on metallic working surfaces; this latter loss alone sometimes amounting to nearly 30 per cent. of the steam used.

By judicious superheating the amount of steam used is decreased by 10 or 12 lbs. per horse-power. The trouble with lubricating oil no longer exists, as mineral oils capable of standing the temperature are easily obtainable. It is only at temperatures exceeding 500° that poppet valves must be substituted for ordinary slide valves.

The average degree of superheat used is from 120° to 150°, and engines are running in which the consumption of superheated steam has been reduced to within a fraction of 10 lbs. per indicated horse-power per hour.

To obtain power economically, all practicable heat must be extracted from the steam. Decrease of heat not represented by useful work is loss; steam must therefore be kept hot until its work is done.

Heat Losses in Steam.—Pressure will be reduced and heat lost in passages of too little area. This may occur if the steam in any part of its journey has to travel at a greater speed than 100 ft. a second; but a more serious loss is the constant condensation in lengths of naked pipe. It seems generally taken for granted that there is equal steam pressure at each end of a pipe, one end being connected to the boiler, and the other to a pump some hundreds of feet down a wet shaft. Under such circumstances the loss may exceed 1° Fahr. for each foot of pipe length.

One horse-power is constantly lost in 152 ft. of naked 2-in. pipe, in 86 ft. of 4-in. pipe, and in 53 ft. of 6-in. pipe. When these pipes are covered with 2 in. of non-conducting composition, it requires over 1,150 ft. of 2-in. pipe to lose a horse-power, 750 ft. of 4-in., and 500 ft. of 6-in. pipe.

Steam, therefore, needs as careful insulation as electricity. It is not a suitable means for power transmission to a distance, but should be used as near as possible to the boiler, the pipes and passages being kept short, as some loss is inevitable, no matter how well clothed they may be.

It is easier to produce steam economically than to make good use of the heat it contains, the most complicated and highly finished engine being a far less economical machine than a good boiler. The latter, as has been shown, utilises from 75 to 80 per cent. of the total fuel value; while an engine working on only 10 lbs. of steam per hour is consuming 1.02 lb. of fuel per horse-power, and utilising less than 25 per cent. of the total heat supplied to it.

The chief loss lies in the heat still present in the steam when it is exhausted at the end of the stroke. Losses by radiation and condensation are also large, especially on those surfaces exposed each stroke to the cooling effect of expanding steam. The cylinder ports and clearance at the ends of the stroke cause losses most noticeable when steam is not used expansively; while before any useful work can be done, the friction of the engine itself accounts for a proportion of the steam admitted, and constitutes the difference between indicated and brake horse-power.

The above losses are inevitable and independent of the working order

of the motor. Should the engine be in bad order, with leaky valves and pistons, and when the action is intermittent, as in winding, the losses become still more serious.

It is safe to say that an engine in bad order, and working under disadvantageous conditions, makes use of less than 5 per cent. of the heat it receives. Some forms of direct-acting steam pump, for instance, use 300 lbs. of steam per horse-power, representing between 40 and 50 lbs. of coal per horse-power per hour.

Loss of Power.—These inevitable heat losses may be minimised as follows:—

1. By placing engine and boiler close together so that the steam pipes and passages are short. The pipes should not be larger than necessary, and should be well covered with non-conducting composition.

2. By a quick piston speed, a small high-speed motor being more economical than a larger and slower running engine.

3. By the use of high pressure, preferably superheated, steam, used expansively, the expansion being carried out in stages, as in the compound system, so that the cylinder walls are not exposed to extreme variations of temperature. As the increased engine friction to some extent counteracts the advantages gained, the compound system is best suited to pressures of not less than 150 lbs.; this is especially the case when the engine is non-condensing.

Steam Motors.—The principal purposes for which power is required are pumping, hoisting, and milling, to which may be added power for distribution in the form of compressed air or electricity. The various forms of engines suitable for the purposes specified being dealt with more particularly in succeeding chapters, it is only necessary to refer briefly to those characteristics desirable in engines for subsidiary purposes.

In all remote districts it is advisable that these be, as far as possible, of one size and pattern, so that not only is a smaller stock of spare parts required, but in case of emergency a part may be borrowed from an engine not in use. This is especially the case with steam pumps for various purposes, including boiler feeding; and complication may be avoided by restricting the number of patterns and sizes in use.

Motors which are self-contained, or stand completely on one base, are preferable to those depending on accuracy in erection for alignment of their parts. Sectionalised machinery is seldom thoroughly satisfactory, a multiplication of smaller units giving better results.

The bearing surfaces must be ample, as lubrication may be irregular, while the margin of strength must be sufficient for rough usage, both during transport, and at the hands of unskilled attendants.

When wrought-iron bed-plates are used, the centre of the engine should

be kept low to avoid warping of the frame, which is liable to occur unless the foundation is of extra strength and the frame soundly secured to it.

Compounding is not to be recommended in subsidiary motors unless the steam pressure is high or condensing gear available.

Obviously the various forms of combined engine and boiler are not best suited for use in tropical countries, especially when, as in hoisting, the attendant has to be constantly at his post.

There seems no reason why small standard engines, such as are ordered from stock, should not be arranged to run in either direction, and crossed belts and other complications avoided at the expense of an additional keyway for the eccentric.

As delivered from the factory, the finished parts are seldom adequately protected from wet during transport. Cases containing highly finished machinery are often dumped on the sea beach below high-water mark, left on river banks, or allowed to stand unprotected for weeks in open trucks and waggons. On arriving at their destination they may not be immediately required, and, for fear of the contents going astray or being used for other purposes, they are not unpacked; with the result that the working faces and polished parts lie rusting in their packing of wet shavings or sawdust. All this might be avoided if machinery shipped to foreign ports were so protected by a coating of white lead and tallow as to stand immersion in water without injury.

On the mine, economy may be gained by doing away with these small scattered motors, working under disadvantageous conditions, and adopting a systematic distribution of power from a central station. Nothing will be gained by merely grouping the boilers, as condensation in long lengths of pipe more than counterbalances any advantage gained. It cannot be too clearly understood that steam is one of the least efficient means at our disposal for distance-transmission of power.

Water.

Water is an economical source of power, and well suited to all forms of mining work. When laying out work in districts where water power is available it will be necessary to ascertain —

1. The quantity of water at disposal, and if that quantity can be increased by storage.

2. The total fall, and whether it can be increased by damming.

3. The reliability of the supply in the driest months of the year, with due regard to the possibility of storage during wet seasons.

Usually reliability is the weak point, sufficient storage being only possible by works of considerable magnitude.

Few companies care to incur the expense of a duplicate installation for steam and water, throughout; but on many mines an intermittent supply

is used for some particular purpose, such as pumping, steam being held in reserve.

Gauging.—The quantity of water may be approximately ascertained in three ways: by measuring the flow through a submerged orifice, the flow over a weir, or by finding the velocity of the current at a spot where the channel is of fairly uniform sectional area.

The first method requires a timber dam thrown across the stream, sufficient in height to destroy the current and pool the water; a square opening of accurate dimensions is cut in the lower part of this dam. The orifice must be sufficiently above the tail-race to afford a clear and uninterrupted discharge, and the sides of the opening must be bevelled outwards, downstream, leaving the sharp edge of the bevel upstream. Having ascertained that the water has ceased to rise behind the dam, or in other words, the opening is passing all the coming water, the depth must be measured from the surface of the water above the dam to the centre of the submerged opening.

The square root of this distance in feet, multiplied by the area of the opening, also in feet, and by the constant 300, will give the discharge in cubic feet per hour with sufficient accuracy for practical purposes.

In gauging by the second method, water is caused to flow over a dam or weir, usually built of planks, the upper edge of the top plank being set level and bevelled downstream as in the previous instance. The dam must be of sufficient height to pool the water and afford a clear drop of a foot or so to the tail-race; in measuring small streams a notch is usually cut in the top plank sufficiently large to pass the coming water.

As the overflow on the crest of the weir cannot be accurately measured from the surface of the passing water, a datum mark exactly level with the top of the weir is set a few feet upstream. The depth of water on this mark being measured, multiply the square root of the cube of the depth in inches by 5, which gives the number of cubic feet of water passing over each foot in width of the weir in a minute.

Or the number of cubic feet per minute flowing over each foot of the weir in width may be found by the following table; the depth being measured, not on the weir itself, but on the datum mark, as described before:—

Depth of Water on Weir in inches.	Fractions of an Inch. 0	¼	½	¾
0	0.0	0.596	1.69	3.1
1	4.78	7.46	9.83	11.1
2	13.5	16.1	18.9	21.7
3	24.8	28.0	31.2	34.6
4	38.2	41.7	44.5	48.9
5	53.4	57.4	61.4	65.4
6	69.4	74.1	78.8	83.6
7	88.4	93.3	98.2	103.0
8	108.0	103.0	118.0	123.0
9	129.0	134.0	139.0	145.0
10	151.0	156.0	162.0	168.0
	Cubic feet per minute.			

Having ascertained the quantity of water and the fall, the horse-power available is found by multiplying the weight of the water in pounds per minute by the fall in feet, and dividing by 33,000.

The result is the actual or theoretical power, of which a motor will yield a percentage, varying according to its efficiency from 60 to 90 per cent. Assuming an average efficiency, the horse-power may be found by multiplying the number of cubic feet of water per minute by the fall in feet and dividing by 700. By this formula, if any two factors are known the third may be found; thus the number of cubic feet of water required to yield a given horse-power on a given fall may be found by multiplying the horse-power by 700 and dividing by the fall in feet. When the power and quantity of water are known, the necessary fall is found by multiplying the horse-power by 700 and dividing by the cubic feet of water per minute.

Forebays.—In laying out the plant the water inlet must be carefully designed, especially when the supply is drawn from mountain streams subject to periodic flooding. Floating material may be caught by screens; they are more effective and less liable to choke when set at an angle than if placed vertically. Precautions must be taken against the accumulation of sand, gravel, and pebbles in the forebay; this is liable to occur whenever the current of the stream is interrupted, as by a dam. The bed of the stream may in this way be silted up level with the crest of the weir, leaving only a narrow channel through which the power supply passes to the intake.

Stones, gravel, and pebbles are capable of doing considerable damage when projected at high velocity against the vanes of turbines or buckets of impact wheels; and even sand rapidly erodes the nozzles through which

the water passes. Such substances should be sluiced out at intervals through gates placed in the forebay for the purpose.

From the intake the water may be conducted in flumes, ditches, or pipes. Ditches are usually led along the hillside, and in steeply sloping ground are seldom satisfactory if cut only partly in the bank, even though supported by a wall on the outer, or low, side. Unless for very temporary use, it will be found cheaper to set the excavation farther back in the bank, so that both sides of it may stand on solid ground. With those inexperienced in hydraulic work there is a tendency to give ditches too much inclination or fall, the result being, not only a loss of effective head, but a rapid current which cuts out the sides and banks. A slope of 1 in 500, or about 10 ft. in 1 mile, will generally be sufficient.

The quantity of water delivered per minute will equal the area of the wetted channel in square feet, multiplied by the mean velocity of the current in feet per minute.

Flumes may be used when rocky ground renders excavation expensive, or when, owing to contours, it is desirable to convey the water above the surface of the ground. In building flumes, square timber frames are made by mortising the top and bottom cross-pieces, and tenoning the two upright posts. These frames are spaced about 4 ft. apart, and the planking placed within them; leakage is prevented by nailing slats over the joints of the planks, or by slightly bevelling their edges, and caulking the joints from within the flume with a strand of tarred marline. Inclinations of 30 and 35 ft. to the mile may safely be given to flumes, provided the head so lost is immaterial. Except where timber is plentiful and iron expensive, pipes are preferable to flumes for permanent work; the original cost may be greater, but that of erection and maintenance is considerably less. Pipes for this purpose are dealt with separately in Chapter XV.

Motors.—The ordinary overshot water wheel is suitable in the following cases:—(1) Where a slow speed is required, as in pumping; (2) when the water supply is abundant (as this form of motor has an efficiency of about 65 per cent. only); (3) when the fall is moderate, as a fall exceeding by more than one-eighth the wheel's diameter cannot be utilised. The two following examples are taken from the mining district of Tavistock, Devon, a locality where water power is largely used for mining work, and where wire ropes and reciprocating rods convey power to great distances in all directions. Pumping wheel—fall, 50 ft.; wheel diameter, 45 ft.; width, 5 ft.; depth of rim, 12 in.; depth of buckets, 15 in.; number of buckets, 90; diameter of wrought-iron axle, 12 in.; 36 arms, each 6 in. square, bolted to cast-iron centres; driving 240 ft. of 12-in. pitwork, and 180 ft. of 9-in. pitwork, with a pumping stroke of 6 ft., and a reserve of power for greater depth.

The dimensions of a wheel used for winding are as follow:—Diameter,

30 ft.; fall of water, 32 ft.; depth of rim, 11 in.; width of buckets, 4 ft.; depth of buckets, 12 in.; number of buckets, 84; 24 arms, each 5 in. square, geared 1 to 2 on to 6 ft. drums; load, 1 ton net.

The fall always exceeds the diameter of the wheel so that the water may fall into the buckets with a velocity slightly in excess of the peripheral speed, and that the lowest buckets may be clear of the tail water.

In gold-mining work water wheels are usually replaced by turbines, as the demand for increased power necessitates either more water or greater motor efficiency.

Turbines.—The principle of the turbine is too well known to need detailed description. The wheel is fitted with inclined curved blades between which the water is directed by gates or guides, these guides being adjustable to suit varying conditions of speed and power. The many varieties arrange themselves into two chief classes—the first containing all those wheels which work by pressure, in which case the buckets must be completely filled, and clearance space minimised. In the other class a jet of water acts on a section of the wheel only at any one time; they are known as impulse wheels; the Girard turbine, Pelton, and Knight wheels belong to this class. Different makes of turbines vary in the direction in which the water acts. In some types, such as the Fourneyron, the water enters at the centre, and the wheel therefore surrounds the guide vanes. In others the guides are above, as the Jonval; or outside, as in the Vortex. Sometimes the water enters from below, and by its pressure relieves the foot-block from the weight of the vertical shaft; this is the case at the Niagara power works.

The efficiency of the turbine is about 75 to 80 per cent. of the theoretical power; 88 per cent. has been claimed in some American tests, and over 90 per cent. has been obtained from Pelton wheels under high falls. As the power available is the weight of the water multiplied by the fall, it follows that a large quantity of water at a small head may be just as effective as a smaller quantity at a higher fall. Turbines can be arranged to work either vertically or horizontally, and are designed for falls of even 3 ft.; at this height 40 H.P. can be obtained from a wheel 7 ft. in diameter, passing 9,500 cub. ft. of water a minute. Vertical wheels are preferable for all low falls.

When mounted in an iron housing, and standing on an iron base-plate, the whole machine is self-contained, and only needs bolting to a level foundation; more care is required when the wheel is placed at the bottom of an open penstock, as the weights and pressures to be dealt with are considerable.

The foundations should be of well-footed masonry, in which the wheel bearers are bedded; these are then decked over, and a hole cut in the decking for the wheel, the edge around the hole being planed true and

level, as the base of the wheel must make a watertight joint when bolted down.

Penstocks may be constructed of timber, provided the head of water does not exceed about 35 ft.; for greater falls pipes are less troublesome. The timber penstock should be of sufficient size to admit of easy access all around the wheel; it is built in the same way as a flume, the frames being stronger, spaced closer together, and strengthened by iron tie-bars in the lower part, where the pressure increases. A vertical shaft, an extension of the turbine axis, passes up through the centre of the penstock, and is supported by bearers at intervals.

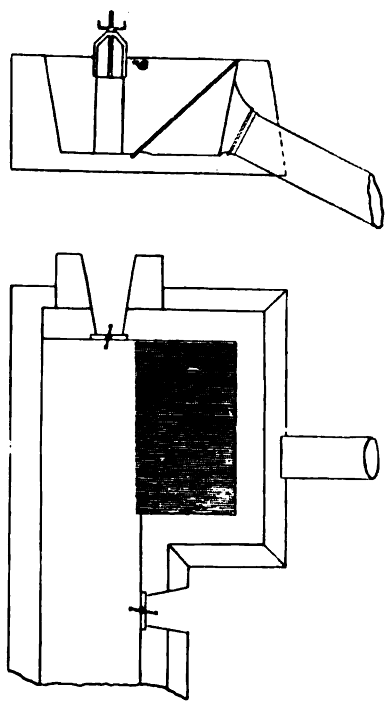


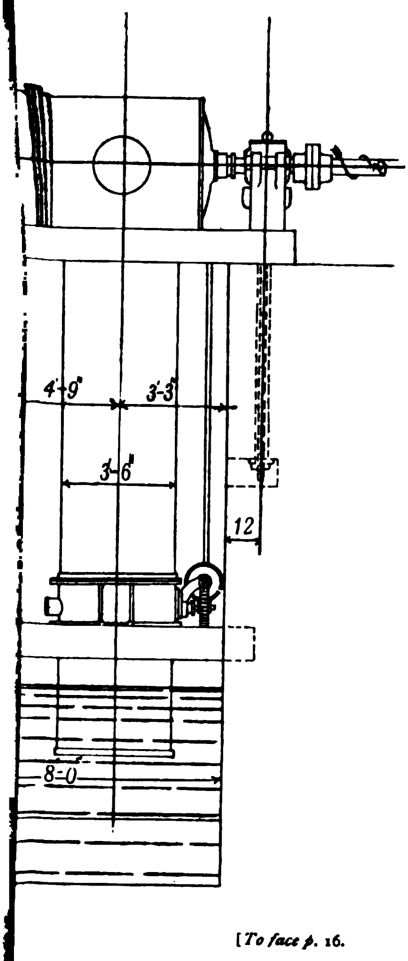
FIG. 1.—Plan and section of Forebay for Turbine illustrated in Figs. 2 and 3.

When pipes are used, the turbine need not be at the lowest point of the fall; the discharge, if piped away, and not exceeding 25 ft. in vertical height, being just as effective as an equal height above the wheel. When the fall below the wheel is utilised, the suction pipe should be carried down well below the permanent level of the water in the tail-race, see Fig. 2.

If the water is properly screened at the forebay, and sticks and stones thus prevented from catching in the vanes, the only part of a vertical turbine needing occasional adjustment is the bearing supporting the shaft. This is either a foot-block, lined with lignum vitæ, and lubricated by water, or is of the suspension type; the latter, being situated above the wheel, is more accessible.

Figs. 1, 2, and 3 refer to a turbine erected on a South African gold-mine. Fig. 1 (drawn to smaller scale than the other two) is the intake or forebay, and shows the screens and sluice gates. Figs. 2 and 3 show the general arrangement of the wheel. The turbine is of the Jonval type, making 200 revolutions a minute, and yielding 300 H.P. on a fall of 57 ft. and a supply of 3,800 cub. ft. a minute; it is mounted on a cast-iron bed-plate bolted to the masonry lining of the pit; two girders, built into the masonry, support the foot of the discharge pipe.

The Single Vortex turbine is suited for low or medium falls; in this pattern the water enters at the outside of the rim, being guided and regulated by four adjustable vanes. The discharge is at the side in



[To face p. 16.

horizontal wheels, and below when they are placed vertically; owing to its large diameter and consequent slow speed it may be used for direct driving in pumping and milling.

The following tables have been kindly supplied by Messrs Gilbert Gilkes & Co., Kendal, who are specialists in this class of work, and makers of the wheels referred to:—

SINGLE VORTEX TURBINES.

Fall in Feet . .	4	6	8	10	12	
Cub. ft. water per min. .	1,765	1,177	883	706	588	10 H.P.
Revs. per min. . .	45	73	91	118	137	
Cub. ft. water per min. .	3,530	2,353	1,765	1,412	1,176	20 ,,
Revs. per min. . .	35	53	71	89	106	
Cub. ft. water per min. .	7,060	4,706	3,530	2,824	2,353	40 ,,
Revs. per min. . .	25	39	52	66	80	
Cub. ft. water per min. .	...	9,412	7,060	5,650	4,706	80 ,,
Revs. per min. . .	...	28	37	48	60	
Cub. ft. water per min. .	...	...	13,240	10,590	8,825	150 ,,
Revs. per min. . .	...	...	28	36	44	

DOUBLE VORTEX TURBINES.

Fall in Feet .	20	30	40	50	60	70	80	90	
Cub. ft. per min.	706	471	353	282	235	202	176	157	20 H.P.
Revs. per min. .	215	300	429	544	600	644	764	810	
Cub. ft. per min.	1,060	706	530	424	353	303	265	235	30 ,,
Revs. per min. .	174	267	347	441	526	568	688	730	
Cub. ft. per min.	1,412	941	706	565	471	403	353	314	40 ,,
Revs. per min. .	158	236	308	389	425	522	607	644	
Cub. ft. per min.	1,765	1,176	883	706	588	504	444	392	50 ,,
Revs. per min. .	145	210	272	340	425	460	491	592	
Cub. ft. per min.	...	1,412	1,059	847	706	605	530	470	60 ,,
Revs. per min. .	...	210	245	300	372	460	491	522	
Cub. ft. per min.	...	1,647	1,235	989	824	706	618	549	70 ,,
Revs. per min. .	...	192	245	300	331	400	491	522	
Cub. ft. per min.	...	...	1,412	1,130	942	806	766	628	80 ,,
Revs. per min. .	...	...	245	269	331	357	430	522	
Cub. ft. per min.	...	...	1,765	1,412	1,176	1,008	882	784	100 ,,
Revs. per min. .	...	...	220	269	298	357	382	405	

Fig. 4 shows the arrangement of the Vortex. The water enters the outside casing at the top—or in any other position that may be convenient—and passing thence is directed by four (or more) guide blades on to the outer circumference of the revolving wheel, which is driven round at a velocity depending on the height of the fall. The water, having expended its energy in giving motion to the wheel, is discharged through the two central openings, half the amount being carried away by each suction pipe. The guide blades, it will be noticed, are movable, and turn about on a pivot placed near their inner ends.

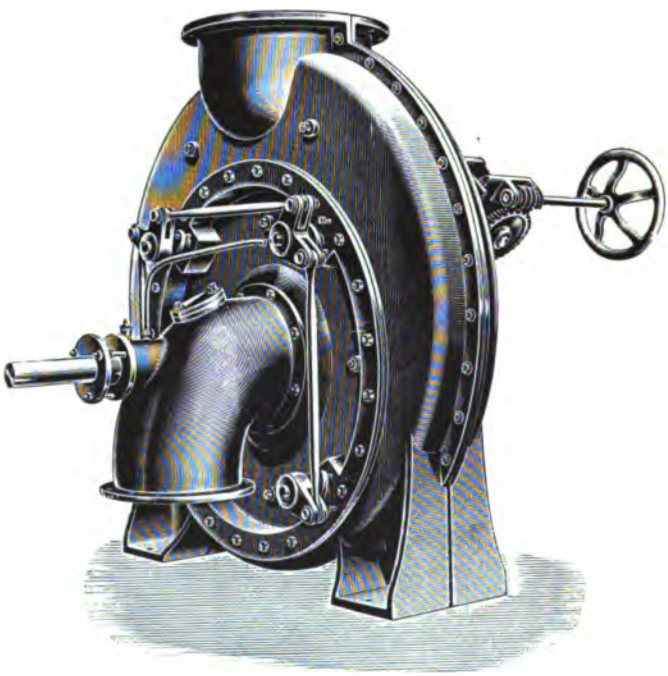


FIG. 4.—Vortex Turbine.

The Double Vortex consists of two separate single wheels, water being received at the outside and discharged on each side at the centre, consequently they are set horizontally. As the speed is higher than in the single wheel, this type is suitable for direct coupling to dynamos; and it is worthy of note that, within limits, they tend to govern themselves to regular speed. When the load is diminished and the speed increases, the centrifugal force of the water carried round by the wheel opposes the entry of further supplies; while if the speed is diminished by increased

load, the centrifugal resistance becomes less than normal, giving greater facility for entry of water, and tending to increase the wheel's speed.

In Girard turbines a jet of water acts on only a part of the wheel's circumference; in this way the high speed due to a considerable head of water on an ordinary turbine is avoided. As the wheel acts by impulse only, all fall below it is sacrificed. The water always passes through the wheel, being received on the inside and discharged on the outside; speed is regulated by reducing the number or area of the jets.

Impact Wheels.—For high falls this form of motor is extensively used, and the Pelton is perhaps the most popular example of this very simple type. In this particular wheel a jet of water is directed against bifurcated cupped buckets attached to the rim; these buckets divide the jet, throwing the water outwards and backwards, clear of the wheel, with the result that the momentum of the water is transferred to the wheel itself.

Nozzles of different sizes adapt the same wheel to varying water supply or power requirements; while the speed can be governed automatically, either by altering the area of the jet or deflecting the nozzle.

Normally the jet is directed in a line tangential to the centre of the buckets, and the speed of the wheel rim is half the velocity of the jet driving it. Impact wheels are suitable for all falls exceeding 50 ft., and under given conditions the number of revolutions per minute made by the wheel depend on its diameter, the resulting H.P. bearing no proportion to the wheel's diameter. The larger sizes may be directly connected to air compressors and line shafting; while, in the case of low falls, two or more wheels may be mounted on the same axle, each being operated by multiple jets, if necessary.

A reversing motion, suitable for hoisting, is secured by arranging a pair of wheels with jets in opposite directions. It is advisable to arrange the drive, should it be a heavy one, so that the wheel may attain its speed before the load is let on either by clutch or shifting belt. Under a constant head of water and a fairly even load the speed is remarkably uniform; while an efficiency of over 90 per cent. is obtainable under favourable circumstances.

The erection of this type of motor presents no difficulty beyond that due to ordinary alignment, to be fully described in following chapters; when wheel and nozzle are mounted on a bed-plate they form a self-contained machine, easily bolted to foundations. Should they be separate, each must be securely anchored, as the pressures due to high fall are extremely severe; and if, through any displacement, the jet no longer strikes the centre of the buckets, the efficiency of the wheel is at once reduced.

Where deflecting nozzles are used, provision must be made for receiving

the jet when directed off the wheel; for high pressures masonry is useless, and the wheel pit should be of sufficient depth to hold a good body of water as a cushion for the jet.

The wear and tear of the wheel itself is practically nil. Nozzles require occasional renewal if the water is gritty, and it is advisable to keep a few spare buckets on hand.

The following examples are taken from gold-mines in various countries:—

Diameter of Wheel in Feet.	Cub. Ft. Water per Minute.	Fall in Feet.	Driving
6	180	254	Forty 750-lb. stamps.
6	150	270	Forty 850-lb. stamps.
5	200	90	30-H.P. air compressor.
18¼	240	730	290-H.P. air compressor.
4	175	415	80-H.P. air compressor and 75-ton concentrating mill.

Fig. 5 represents a Pelton wheel with the housing removed; it is designed to yield 60 H.P. on a 200-ft. fall, the speed being 225 revolutions a minute, and the water supplied through 11 and 12 inch piping.

In the table given on the next page it may be noted that, at 700-ft. fall, each cubic foot of water per minute yields 1 H.P., and at 350-ft. fall, half a horse-power—facts easily remembered and useful in rough calculations. As an instance of high fall, a Pelton wheel at the Colmstock mine worked under a head of 1,500 ft., and yielded 4¾ H.P. on 1½ cub. ft., or about four buckets of water a minute. This, however, is by no means the limit. Jets under a vertical head of 1,960 ft. are in use, the pressure at the nozzle being 850 lbs. to the square inch, and the velocity of the jet approaching four miles a minute.

Pelton Wheel Table.

Diameter of Wheel in Ins.	Fall in Feet	100	200	300	400	500	600	700
15	Cub. ft. per min.	16	23	27	32	37	40	43
	Revs. per min.	613	867	1,060	1,228	1,370	1,500	1,620
	Horse-power	$2\frac{1}{4}$	$6\frac{1}{2}$	$11\frac{1}{2}$	$18\frac{1}{2}$	26	34	42
18	Cub. ft. per min.	28	42	49	58	65	70	75
	Revs. per min.	510	720	884	1,021	1,142	1,251	1,351
	Horse-power	4	$11\frac{3}{4}$	21	33	47	60	75
24	Cub. ft. per min.	49	74	89	104	115	129	135
	Revs. per min.	382	541	663	765	856	938	1,013
	Horse-power	7	21	38	59	82	110	135
36	Cub. ft. per min.	113	166	205	238	266	287	310
	Revs. per min.	255	360	440	510	571	625	675
	Horse-power	16	47	87	135	190	245	310
48	Cub. ft. per min.	205	296	364	414	462	515	550
	Revs. per min.	191	270	332	383	429	4'9	506
	Horse-power	29	84	155	235	330	410	550
60	Cub. ft. per min.	325	466	564	660	735	790	850
	Revs. per min.	153	217	266	307	343	376	406
	Horse-power	46	132	240	375	525	675	850
72	Cub. ft. per min.	473	670	822	931	1,064	1,147	1,250
	Revs. per min.	127	181	221	255	285	312	337
	Horse-power	67	190	350	535	760	980	1,250

Gas, Oil, and Petrol Motors.

All these motors are self-contained, easily erected, require no boiler, use fuel which is lighter than and more easily handled than coal or wood, and require no more skilled attention than an ordinary steam-engine. For these reasons they are well adapted for districts where coal and wood are scarce, and transport costly; also for preliminary work, and as auxiliaries in mines not possessing a power distribution system. Their weight is generally less than that of a steam-engine and boiler of equal power. Few gold-mines are so fortunately situated as to be supplied with gas, but with the adoption of the suction gas system, this type of motor seems likely to come into more extensive use. Petrol is not largely used, partly on account of the excessive transport charges. But all these motors are so alike in their action and arrangement that a description of one serves for the others also; with unimportant exceptions, they are all on the four cycle principle—that is to say, the piston receives only one impulse in four strokes.

The explosive mixture is admitted to and exhausted from the cylinders by two ordinary mushroom valves, which are closed by springs, and opened

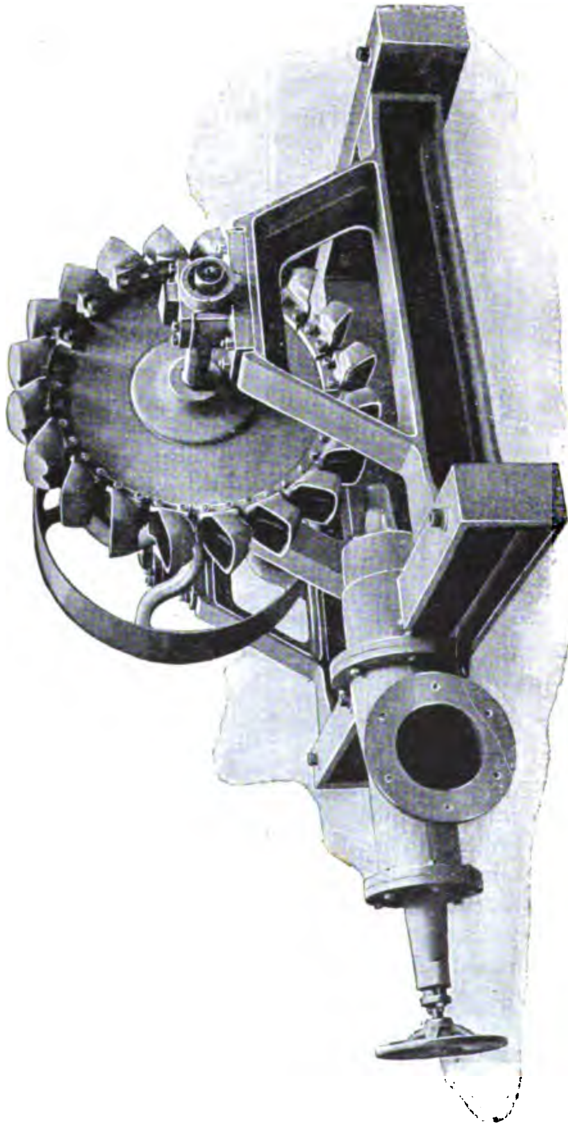


FIG. 5.—Pelton Wheel with Housing removed.

by cams mounted on a shaft geared to make one revolution to two revolutions of the engine.

The cycle of movement is as follows :—As the piston recedes from the back cover the explosive mixture is drawn in through the inlet valve ; on the return stroke the charge is compressed to from 60 to 120 lbs. per square inch, and fired as the stroke is completed. The following outward movement is the impulse stroke, made under pressure of the exploded gases ; at the termination of the stroke the exhaust valve opens, and the return movement of the piston clears the cylinder for the next charge. The chief difference between gas, oil, and petrol motors lies in the way in which the explosive charge is prepared. In gas engines the gas is mixed with sufficient air to form an explosive mixture, after its pressure has been regulated by passage through a rubber bag. In engines using oil, the supply is atomised, either by a jet of compressed air or by passing through a heated vaporiser ; the oil may be kerosine, or the less refined varieties, and is usually supplied in the quantity sufficient for each stroke by a pump controlled by the governor.

Petrol motors draw their supply through a carburetter, in which the spirit is sprayed and automatically mixed with the necessary air. In all these motors the explosive charge is fired in one of two ways ; either by a tube kept hot by a Bunsen burner, or by an electric spark ; the latter is more certain in its action, more easily regulated, and is gradually replacing tube ignition. Electricity is supplied either from a primary battery or by an accumulator charged at intervals ; during its passage to the spark plug its voltage is increased by a transforming coil. It is generally easy to change from tube to electric ignition by screwing a spark plug in place of the tube and supplying the necessary current of four to six volts. Motors of this kind are easily fixed, as they are all self-contained ; but owing to their irregular impulses, they need substantial foundations. Starting is usually effected by giving the flywheel a few quick turns by hand, only the larger sizes being fitted with self-starters.

Should the cam shaft be removed at any time, care must be taken that it is replaced with the same teeth of the wheels in gear ; a tooth on one wheel and a space on the other are usually marked for this purpose. If these marks cannot be found, the wheels should be so meshed that the inlet valve lifts as the piston completes its backward stroke, and the exhaust valve just before the forward stroke is finished. Compression is the life of the motor, and can be roughly tested by the resistance felt when the engine is turned slowly by hand. High compression means economy in fuel.

In the Diesel engine the charge is compressed to 500 lbs. per square inch, and the heat generated in compression is sufficient to fire the charge. To ensure good compression the piston rings must fit with exactness in their grooves, yet be free to expand ; new rings need careful bedding by filing and scraping. The valves need an occasional grinding to clear their beats, and when resting on their seats their stems should be a thirty-second of

COMPOSITION AND CALORIFIC VALUES OF VARIOUS GASES.*

Gas.	Process.	H	CH$_4$	CnH$_2$n	CO	N	CO$_2$	O	H$_2$S	Percentage of Combustibles.	Calorific Value B.Th. Units per cubic foot of gas.		Volume of Air required to complete Combustion.	Calorific Value B.Th.U. per c. ft. of Gas and Air Mixture.
		Hydrogen.	Marsh Gas.	Heavy Hydro-carbons.	Carbon-Monoxide.	Nitrogen.	Carbon-Dioxide.	Oxygen.	Sulphuretted Hydrogen.		Gross.	Net.		Net.
		Combustible Gases.				Incombustible Gases.								
Natural Gas	. . . . . .	2.18	92.6	0.31	0.5	3.61	0.26	0.34	...	95.6	969	876	8.98	87.7
Coal Gas (London)	Air-tight Retorts	52.9	31.8	5.0	7.18	2.5	...	...	...	97.0	610	544	5.22	87.4
(Birkenhead)	Air-tight Retorts	47.69	35.75	4.88	5.99	4.76	...	0.94	...	94.3	628	560	5.42	87.0
(Manchester)	Air-tight Retorts	42.9	30.93	6.8	14.99	2.24	2.14	...	...	95.6	642	573	5.33	90.5
Coke Oven Gas	. . . . .	53.0	35.0	2.0	6.0	2.0	2.0	...	..	96.0	592	522	5.06	86.2
Carburetted Water Gas	. . . .	40.2	16.8	8.72	28.74	5.38	...	0.14	...	94.5	544	496	4.5	90.0
Water Gas	Steam through incandescent coke or coal	46.3	1.3	...	45.6	4.3	2.1	Trace	0.4	93.2	317	290	2.3	87.0
Oil Gas, gasified petroleum	. . .	31.61	46.17	17.02	0.14	5.06	...	...	...	95.0	860	774	7.6	90.0
Wood Gas	Riché distillation Air-tight Retorts	45.0	15.0	...	22.0	...	18.0	...	...	82.0	377	336	3.0	84.0
Wood Gas	Riché Combustion Steam and Air . .	12.2	1.0	3.4	11.6	62.5	9.3	...	...	28.2	144	133	1.15	61.7
Producer Gas—Siemens Air Blast	.	8.6	2.4	...	24.4	59.4	5.2	...	...	35.4	134	128	1.02	59.0
,,	Pressure and Suction Plants Steam and Air	18.7	0.3	0.3	25.1	49.0	6.6	...	...	44.4	152	141	1.07	70.0
,,	Mond Steam and Air . .	27.5	2.0	...	11.0	43.0	16.5	...	...	40.5	148	131	1.13	61.5
Blast Furnace Gas	. . . . .	6.8	1.4	...	23.0	59.8	9.0	...	...	31.2	112	107	0.85	58.0
Acetylene	. . . .	C_2H_2 100.0								100.0	...	1558	12.5	115.0

* From "Gas Producers for Power Purposes," by W. A. Tookey.

an inch clear of the lifting tappets. Free circulation of cooling water around the cylinder is necessary, and is usually obtained from a tank, the cool supply being drawn from the bottom and returned to the top of the tank. The word "cooling" is used in a relative sense only, a constant supply of cold water being detrimental; most motors work best when the cooling water is about as hot as the hand can bear.

Lubrication is another vital point, as all motors of this class need a regular supply of suitable oil fed through an automatic lubricator. If the oil is unsuitable, or if too much is used, the interior of the motor becomes covered with a deposit of burnt oil. Heating of the engine and premature ignition will result if this deposit is not cleaned off at intervals; heating may also be caused by too rich an explosive mixture.

There is nothing mysterious about these motors; they work regularly if the necessary conditions are fulfilled. Provided the lubrication is good, and the working parts in proper order, valves and piston tight, the only things likely to cause trouble are the mixture and the firing.

The firing tube may be cracked, may not be high enough, or not a bright red heat; many new tubes split when first put in because they have not been thoroughly dried beforehand. Electric firing is easily tested by unscrewing the plug and seeing that it sparks when connection is made with the coil; the two sparking points should be $\frac{1}{32}$ of an inch apart. Again, an accumulation of grease or dirt on the commutator may prevent proper contact being made; it is also necessary to see the timing correctly set, so that the firing occurs on the completion of the compression stroke.

Trouble is more likely to be caused by a mixture containing an incorrect proportion of gas, known as too weak or too strong a mixture. This is tested by altering the air admitted at the air inlet until the result is satisfactory. Valve springs need occasional changing or adjustment to ensure that the valves close sharply, and none of the charge is lost by their tardy movement. Exhaust pipes should be kept clear of timber work, and the sound may be muffled by leading the pipe into a perforated drum filled with coke or old chain.

Electricity.

The following remarks are in no way intended to replace the fuller information contained in books devoted to the subject, but no description of mining machinery would be complete without reference to this valuable medium for transmission and distribution of power. In its wider applications electricity must be a special branch of engineering, but its use in mining is becoming so general that mining men will find some knowledge of its principles absolutely essential.

Perhaps the first step in this direction is a clear conception of a few of the terms used in speaking of electric currents; these are more readily understood when compared with similar terms used for steam and water power.

The Volt is the unit of electromotive force and corresponds with strength or pressure, with the height of the fall in case of water power. The voltmeter measures the voltage or strength of a current, just as a steam gauge shows the boiler pressure.

The Ampere is the unit of quantity, and corresponds with the amount of water available. Just as equal effects may be produced by large and small quantities of water falling through unequal heights, so in electricity the current may be many amperes at a low voltage, or few amperes at high voltage, yet each may be equal to the other, and may be transformed into the other. **The Ammeter** measures the amperage or quantity of electric current.

The Watt.—The available power of a waterfall is estimated by two factors, weight and fall, multiplied together; so the electric current is measured by volts multiplied by amperes, the resulting figures being termed watts. The watt is therefore a measure of electric power, and 746 of them are equal to an indicated horse-power.

Conductors.—Like water, electricity tends to equalise itself and flow from points of greatest pressure; in doing so, it follows the line of least resistance, and its passage from point to point is called a current. Substances that offer little resistance are called conductors; those which are such bad conductors that they practically prevent the flow of electricity are known as insulators. Among the former class are the metals; among the latter, glass and vulcanite. The resistance offered by a conductor of any given material is in proportion to its length and in inverse proportion to its sectional area. The operation of conveying electricity may be compared to the passage of a liquid through a pipe, and we know that an increased head is necessary to pass a given quantity of liquid through a smaller pipe.

Circuits.—In practice the conductors take the form of wires, and in its passage through them the current forms a circuit. When the lamps or motors form connecting links between the two wires, the circuit is called "parallel"; when they are arranged one after the other on the same wire, the arrangement is known as "series."

A Dynamo in its simplest form consists of a pair of magnets, and

a number of conductors which cut or interrupt the lines of attraction between these magnets. In practice, the conductors would be bound together into a revolving armature, while the magnets are wound with wire to increase their attractive power. The current in the armature is collected by brushes, and may be of two different kinds. In the course of every revolution each conductor will cut the field between the magnets in two opposite directions, upwards and downwards. If the current generated in each direction is collected separately, the result is an *alternating current*. On the other hand, by collecting the current through a commutator formed of insulated bars, the brushes can be arranged to take up current in one direction only, and be insulated or out of gear when the conductor is moving in the opposite direction; the result in this case is a *continuous* or *direct current*.

It must be understood that by reversal of current the dynamo becomes a motor, and *vice versâ*. Both machines are alike in all important characteristics, and differ only in minor constructional details.

The Armature of a dynamo or motor consists of a central core around which the insulated conductors are arranged. In ring armatures, the conductors are wound around a ring. In the more common drum armature, the core consists of a number of iron discs, each insulated from the others; upon these the conductors are wound in layers, the current generated in each coil of conductor being conveyed to the insulated commutator, and there collected by the brushes.

The Magnets, of which there may be two or more, usually in pairs, are wound with wire so that they may be excited in different ways. When the field magnets are "series" wound they are covered with a few turns of large wire conveying all the current generated. The strength of the magnets, therefore, varies with the current, and this form of winding is suitable for great variations of load.

Shunt-wound magnets are covered with many turns of fine wire, through which a portion of the current is sent, or shunted; as the small wire offers considerable resistance, the degree of excitation is practically uniform and in inverse proportion to the current generated, being relatively weakest when the current is strongest.

In compound winding both the above systems are used, so that the increased strength of the series winding may be balanced by increased proportional weakness in the shunt winding, and a uniform output maintained.

Fixing.—Dynamos and motors may be either directly connected, or may receive or deliver power through a belt; in the latter case they are generally mounted on sliding base-plates controlled by parallel screws, and

in either case a solid foundation is required to absorb vibration. Concrete is the best material for the purpose; small machines may be placed above the foundation pit, the anchorage bolts dropped into position, and the concrete bedded around them.

For larger machines the foundation must be laid out with bolt and crow holes, as described in engine erection. The machine should stand at a convenient and accessible height above the floor, the base-plate being accurately levelled and grouted beneath the pure cement. The alignment of the machine is described in the chapter dealing with shafting.

Before starting the machine careful inspection will be made to see that none of the wires or connections have been damaged or broken in transit, and that it has been thoroughly cleaned of all dust, dirt, chips, and packing material. The brushes require setting like the valves of an engine; for this purpose they are mounted on rockers, and two marks made on the commutator. The armature should be turned until these marks are horizontal, and the brushes set in their rockers so that their tips are level with the marks. Care must be taken that the brushes are squarely fixed in their holders, and bear their whole width on the commutator.

Even when connections are right and contacts clean, new machines may fail to excite; when this happens current must be supplied to the magnets from a primary battery or another dynamo. Failure to excite may also be due to insufficient speed.

Motors at work.—When at work, with the exception of lubrication, the brushes and commutators require most attention; the amount of sparking is a fair guide to the adjustment and condition of the brushes, and the rockers should be gradually shifted until sparking is minimised.

Sparking may also be caused by too light contact, or insufficient area of contact between the brushes and commutator, while too heavy a contact results in unnecessary wear. When in good order the commutator looks like burnished copper. Roughness or small grooves may be removed by a fine file followed by emery cloth used when the machine is revolving; but should the commutator be badly cut, it may be necessary to turn it up by using a slide rest temporarily bolted to the bed-plate.

Before stopping, the speed should be reduced, switches opened, and brushes lifted when the machine is nearly at rest. When not in use, it is a good plan to keep the machine covered up and protected from oil and dust, a very thin layer of this mixture on some parts being liable to cause short circuit and serious damage.

On leaving the dynamo the current passes to the switch-board, to which the circuits are connected, and from which they are controlled. Each circuit may be provided with a rheostat, to regulate the potential by interposing resistance, and with fuses which melt and cut off the current in case

of overheating. Motors are often provided with multiple switches, so that the current is gradually applied and damage to insulation avoided. For

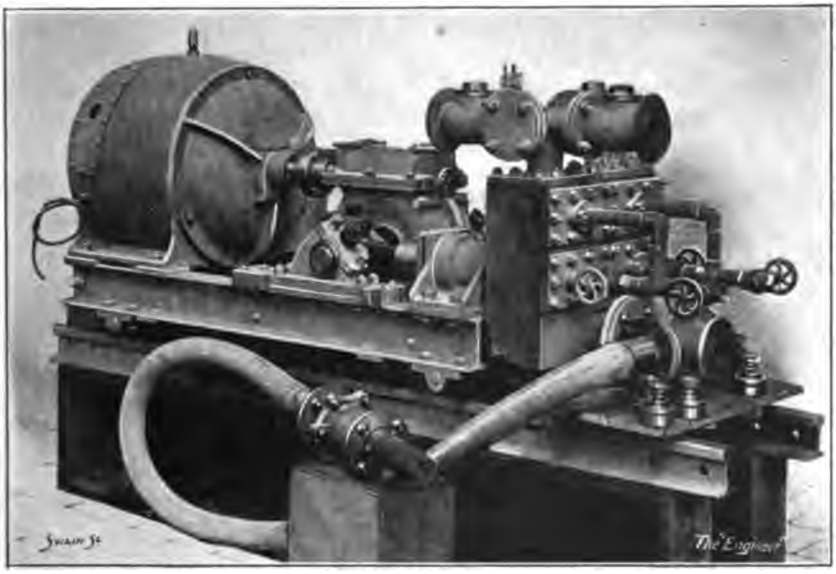


FIG. 6.—Two-throw Electric Pump.

FIG. 7.—Three-phase Winding Engine.

ordinary lighting and distribution of power 110 and 220 are the voltages generally used, potentials which do not need the special precautions

necessary in dealing with high voltages, such as are used in distance transmission of power.

When used for power purposes only, the three-phase system is generally admitted to be most suitable, as effecting a considerable saving in conductors; but should light and power be required from the same circuit, the two-phase system is preferred.

Electricity is a suitable medium for conveying power to isolated work, such as subsidiary shafts, or diamond drills, and may be applied wherever motive power is needed. As the motor revolves at a high speed it is directly connected to centrifugal pumps and ventilating fans; but when the turning moment of the load is heavy, gearing is necessitated by the

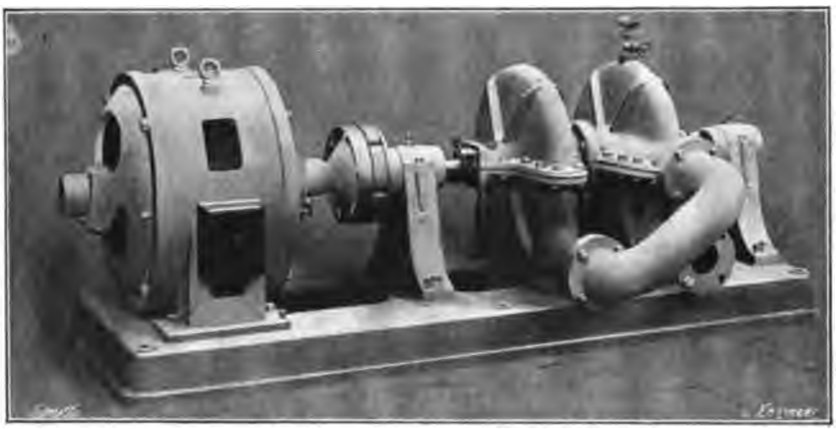


FIG. 8.—Two-throw Electric Centrifugal Pump.

small torque applied. This complication is gradually being removed; trams are running in which the gearing is only four to one, while in some cases the motor is coupled directly to the car axle.

Inevitable losses occur in every transformation of power, and in the use of electricity these losses are due to the friction of the machines, resistance in machines and conductors, and leakage through imperfect insulation. Thus in driving a dynamo by water power, the water motor may develop 80 per cent. of the power applied to it, while the dynamo yields 85 to 90 per cent. of the power it receives. This percentage is subject to further deduction for losses in transmission, and in converting the current into useful work at its destination.

Electric Pumps and Hoists.—Figs. 6, 7, and 8 illustrate electric motors as supplied to pumping and hoisting by the Sandycroft Foundry, Chester, a firm who have taken a leading part in the application of

electricity to mining purposes. These machines can be arranged either for direct or alternating current. The firm in question also make a very compact liquid starting switch for three-phase currents. The principal features of this switch are: absolute freedom from sparking, contacts do not require renewal, no evaporation of liquid, cannot be burnt out, and can be arranged for pressure up to 550 volts by simply altering the strength of the solution.

CHAPTER III.

ENGINE ERECTING.

Foundations, Setting Out, Material for—Laying Out and Building Foundations—Erecting Engines—Lines—Levelling—Aligning the Crank Shaft—Centring Guides and Cylinders—Placing Engine on Centres—Assembling—Valve Setting—Jointing—Adding a Second Side—Adding a Second Cylinder in Tandem Position.

Foundations.—In building foundations the main objects in view are—

1. To form an unyielding bed for the support of the machinery.
2. To absorb vibration.
3. To resist the pull when power is transmitted beyond the base of the engine, as is the case in pumping, winding, and driving by ropes and belts.

In erecting, not only must the various parts be correctly assembled, but the whole machine must be correctly placed with regard to the direction in which power is to be delivered. This direction corresponds with the datum line from which the work is laid out, and should be fixed with such permanency that reference to it is possible until the work is completed. Details may differ with the size, shape, and purpose of the motor; but the principles involved remain unaltered. For the purpose of illustrating these principles it will be sufficient to describe the erection of a pair of Corliss engines, as this pattern is made in three trunk pieces and presents perhaps more difficulty than the ordinary engine mounted on a bed-plate.

Assuming that the engines have to be connected with a mine shaft, the first requisite will be a base line, connecting the two, from which the work will be laid out. This line is easily obtained by the help of a theodolite, set up on and squared with the collar of the shaft; the exact station of the instrument will depend on the purpose for which the engine is to be used. If for winding, it is set up in the centre of the winding compartment, or midway between them if there are two compartments. In setting out for a pumping engine, the theodolite is fixed at the same distance from the end of the shaft as the centre of the pump rods will be. It is not always safe to assume that the collar is square with the shaft itself, and a small error on so short a base is magnified when the line is extended one or two hundred feet. Plumb lines may be dropped down the shaft to guard against error from this cause.

In incline shafts a sight may be taken to a candle, placed a hundred

feet or so down the shaft, and the same distance from the end of the shaft as the instrument is set; the reversal of the telescope, if the theodolite is level, will give the required direction. The line so obtained will be the direction required, and may, or may not, correspond with the centre of the engine to be erected; it will be so if the engine is direct-acting, and will not be should gearing intervene between the engine and the pumping shaft or winding drums.

In order that this direction, or datum line, may be preserved for reference, a stout post is fixed in the ground, at least 10 ft. nearer the shaft than the proposed excavation, and another at least 10 ft. farther away. The tops of these posts being sawn off level, a nail is inserted in each by an assistant, who holds it exactly in line with the centre web of the telescope. A fine line or piano wire, stretched between these nails, will coincide with the direction given by the theodolite.

The theodolite may be considered almost a luxury. It is, of course, possible to dispense with it and to obtain the line from bobs, hung at the collar and carefully squared with the shaft itself. From a position well behind the plumb lines, sight should be taken along them, while an assistant adjusts the posts and nails in position. This method is preferable to any attempt at projecting so short a base by stretched whipcord, which, in exposed places, is liable to deflection and vibration through wind pressure.

Alignment being secured and the requisite distance measured off, the site of the excavation may be pegged out, allowance being made for any difference between the centre common to the pair of engines and the datum line. Let the excavation be at least 2 ft. greater on each side than the measurement of the masonry to be built.

The sides and ends of the pit will be lines either parallel with the original datum, or at right angles to it; those at right angles are set off by a square with sides at least 4 ft. long, by theodolite or optical square, or by application of Prop. 47, Euclid I. In the latter case the lengths 3 and 4 may be taken as bases and 5 as the tie line; any multiple of these numbers does equally well.

The excavation will be carried down to firm picking ground, preferably rock or gravel. When a firm bottom cannot be reached within reasonable depth, it may be necessary to extend the dimensions of the pit, so that the weight is distributed over a large area; in bad cases piles may be required.

Materials for Foundations.—As building stone can generally be obtained near at hand, most likely from the mine dump, foundations or "loadings" are usually built of stone, though concrete is used where skilled labour is scarce, and is equally effective.

In some countries, where lime and cement are practically unobtainable, timber frames, or "horses," are laid on bearers in the foundation pit, and

filled around with rock. No matter how well fitted or braced these frames may be, play is always liable to develop in the joints. Under such circumstances, perhaps, the soundest timber foundation is made of a crib work of heavy squared logs forming a box; bearers are provided below for anchorage of foundation bolts, and above to carry the engine. The bolts pass right through from top to bottom, binding the whole together, and the interior is filled with stone broken to the size of road metal.

Foundations of this kind have been successfully used in the gold-mines of Venezuela.

Laying out Masonry.—If masonry is to be used, the pit is first levelled up by a paving course, or by concrete filling; pointed plumb bobs are suspended from a wire stretched between the datum points, and that line transferred to the bottom of the pit. The ends of a straight-edge are brought to coincide with the plumb bobs, and the line traced in damp mortar by a sharp trowel.

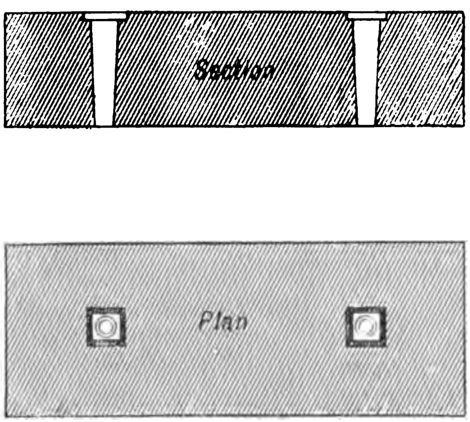


FIG. 9.—Concrete Sole-plate.

From this, it is easy to set off parallel lines indicating the centre of each engine and the width of the masonry blocks; a line at right angles to these, and at the correct measured distance from the mine shaft will be the centre of the crank shaft, and it should be fixed for reference, as all longitudinal measurements are made from it. Across each block of masonry are marked the spaces for the crow holes, their sides being parallel with the crank shaft line, and each being the correct distance from that line.

Footings.—The first or footing course may now be laid and carried up level with the tops of the crow holes, usually 12 or 15 in.; above this, the masonry is often set back on each side, the object of the extended footing course being to distribute the weight.

Sole-Plates.—These are the anchorage blocks through which the holding-down bolts pass, and must now be put in place. They may be slabs of stone with holes drilled through them, or blocks of concrete made

in rough timber moulds, the holes being cored out and a shallow recess left around each hole to take the foot of the pipe. When bolts are spaced closely together, it is often advisable to anchor two or more of them to the same slab.

Fig 9 shows a concrete sole-plate: the section illustrates the depressions left around the bolt holes to receive the pipes, while the plan shows these pipes in position.

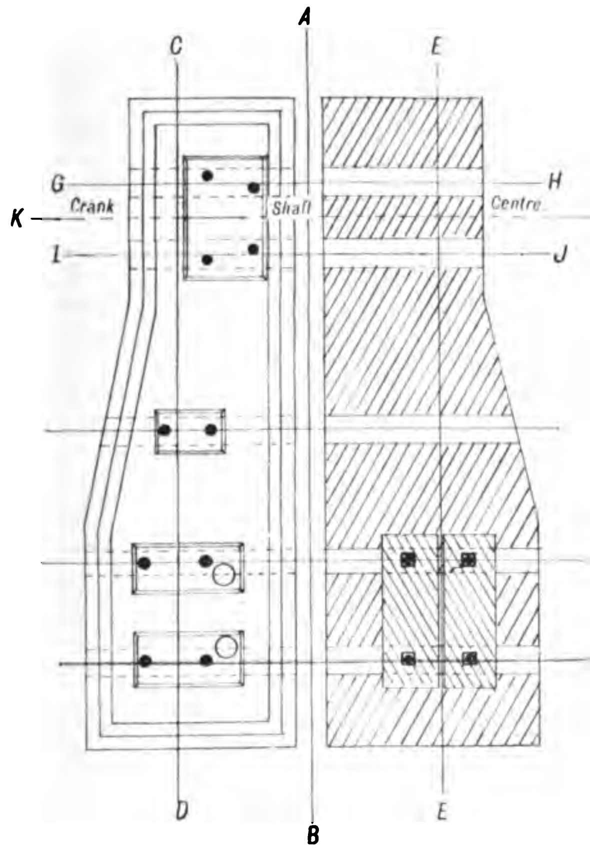


FIG. 10.—Plan of Engine Loading.

The masonry has now reached the stage illustrated on the right-hand side of Fig. 10, and we now require to reproduce the centre lines at a height not much above the tops of the sole-plates; ordinary whipcord answers very well for this purpose. In Fig. 10 the line A B is the common centre of the engines, the datum from which all transverse measurements are made; it is either the original datum line or one parallel with it.

The line K L is the centre of the crank shaft, and from it all longitudinal measurements are made. We will assume that the first pair of holding-down bolts for the main bearings are each 2 ft. from the crank shaft centre, and 5 ft. distant from the common centre of the pair of engines.

On a staff with at least one edge truly planed, pencil marks are made at 0, 5, and 10 ft.; it is then placed so that the 5-ft. mark corresponds with the centre line A B, and its planed edge is parallel with and 2 ft. distant from the crank shaft line K L. The sole-plates are now brought into position until the centres of their holes correspond with the pencil marks on the staff, care being taken that the latter is replaced in its original position should it be shifted by the movement of the sole-plates. Fig. 10 shows two sole-plates for the right-hand cylinder in position.

In this manner, proceeding from the crank to the cylinder end, the sole-plates are separately brought into place, the right and left hand sides being adjusted by one measurement made from the common centre A B; while the longitudinal distances are all referred to the crank shaft line K L. Should there be any doubt about the accuracy of the work, it may be checked by a wooden template made from the engine bed, but this is not necessary.

The masonry may now be carried up another course, level with the tops of the sole-plates.

The timber pipes, through which the holding-down bolts pass, are about 3 in. square inside, 4 in. square outside, and of sufficient height to reach to the top of the loading, less the depth of the cap stones. Their feet rest in the depressions made for them, keeping them concentric with the bolt holes; when the sole-plates are stone slabs, care must be taken that the masons do not shift these pipes in building the first course or two.

When the feet of the pipes are steadied by a course of masonry, their upper ends must be braced in both directions, that they may not be deflected from the vertical during the building of the loading. Narrow strips of boarding, about 2 by $\frac{3}{4}$ in., are used for this purpose; on each strip is marked the exact distance apart of two or more holding-down bolts, and a wire nail driven just through the strip at each mark. Having pencil-marked the centre of the pipes near their upper ends, apply the strip so that the nail points correspond with the marks, and nail fast. In large work strips are advisable on each side of the pipes.

The line of pipes, being thus correctly spaced, must now be secured in a vertical position by struts at each end of the loading. In the same manner the different rows are spaced crossways, and strutted to the sides of the pit; here again the accuracy may be checked by template if desired.

Fig. 11 shows the foundation with two pipes in position on the left or

sectional part of the illustration; this figure is reproduced at rather smaller scale than Fig. 10.

Building.—As the work of building proceeds, the levels must be checked from time to time, that recesses may be left where required for pipes, brake beams, dash pots, or crank pins. When concrete is being used, wooden moulds of these recesses are prepared; in large masses of concrete it is economical to introduce blocks of stone, or "plums," into the body of the work. Each block should be thoroughly cleaned and roughly dressed, to ensure the adherence of the concrete bedding.

In ashlar facing the stones comprising each course should be, as far as possible, of one height; the vertical joints should be square with the course, and fall on the centre of the stones below. In any case, a continuous line of vertical jointing should be avoided.

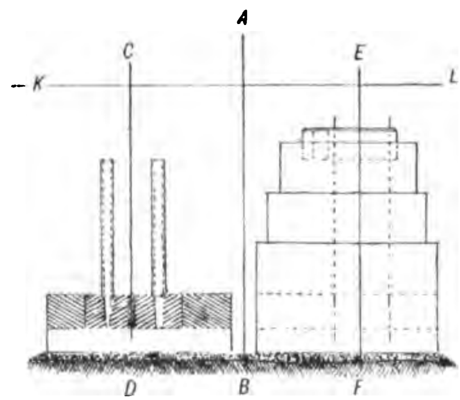


FIG. 11.—Cross-section of Loading.

Bond stones, introduced at intervals, serve to tie the face to the body of the work; and as the face of each course is completed, the interior is filled with well-bedded stone set in mortar, and the whole course flushed level with chips and mortar.

The tie-pieces between the pipes are removed as the work advances, and a set back is usually left at the floor level of the engine-house; the cap stones, either dressed stone or concrete, and provided with holes for the bolts, must be carefully bedded and levelled; they are almost counterparts of the sole-plates appearing in Figs. 10 and 11. For small work a wooden frame is sometimes substituted for cap stones. Finally, the masonry should be allowed time to harden and settle before any machinery is placed on it.

The Engine.—The following remarks apply equally to every class of engine, and, granted good design, sound material and workmanship, the life and duty of the engine depend on the accuracy with which its erection is performed. Unfortunately, this work is sometimes undertaken by men who have no experience to guide them, and do not realise the principles involved. The author has seen horizontal condensers disconnected, being so much out of line that air-pump rods only lasted a few months; tandem compounds with the low-pressure cylinders disconnected for the same

reason; connecting rods heated and bent in endeavour to bring the big ends into line with the crank pins; to say nothing of a mill engine that would not run without its load on less than 40 lbs. of steam, and was fed for days with a mixture of sand and water in vain attempt to grind the bearings into alignment.

In engine erecting accuracy does not mean something that can be measured with a 2-ft. rule, but a few thousandths of an inch measurement only to be obtained by the careful gauging of a trained hand.

When the top of the loading is some height above the ground, the various parts of the engine may be raised into position in several ways. Heavy and unwieldy pieces, such as bed-plates, may be hauled up an inclined plane built at the end of the loading; pieces of awkward shape, as cylinders and condensers, may be mounted on skids and fed with rollers. Usually all parts can be dealt with one or more pairs of shear legs, which, when properly controlled by block and fall guys, can be swayed a considerable distance on each side of the vertical, thus covering a much larger area than a fixed tripod. When the walls of the engine-house are already built, the hoisting gear may be suspended from cross beams resting on temporary wall-plates, to distribute the weight and protect the walls from injury.

Assuming the different main parts of the engines to be resting on the loading, the main bearings, cylinders, and guides are roughly in their respective positions, and their bolt holes corresponding with those in the cap stones; bolt these parts together, and place the crank shaft in its bearings.

In addition to the ordinary gear and tackle, the following tools will be required:—A fine silk line or coil of piano wire; a brass level with ground bubble; two plumb bobs with silk or thread lines; a staff planed true and parallel throughout its length; about thirty wrought-iron wedges, each about 2 in. wide by 6 in. long, $\frac{3}{8}$ thick at the butt, and tapering to the point.

Setting Lines.—Whether the engine is to be in line with some particular point in the mine shaft or parallel with an existing run of mill shafting, the line to which it must conform will be that laid down when the work was begun. This line must now be reproduced by a wire stretched the full length of the loading, and as near the centre of the engine as the diameter of the crank shaft permits. Accuracy is attained by plumbing from this wire to one stretched between the permanent datum marks below, the upper wire being shifted until their alignment agrees. The line thus placed will be A B in Fig. 10; two other lines C D and E F, parallel with A B, will be required to represent the respective engine centres. But as these intersect the paths of the crank pins and prevent the shaft from being rotated, it will be advisable to put up only one at a time.

Too much care cannot be exercised in correctly placing these wires, as all measurements about the engine will be referred to them. Perhaps the most convenient plan is to fix a stout plank at each end of the loading, and, with the help of a spirit-level, make a horizontal mark across each plank at the same height above the cap stones as the engine centre. Measuring from the common centre of the engines with a staff correctly marked, lay off on these lines the correct distance of each engine from the common centre, and bore 1½-in. holes through the planks at the points of intersection.

The wire is now reeved through the guides, cylinders, and condenser, passed through the holes in the planks, made fast at one end to a piece of round iron, while the other end terminates in a ¼-in. straining bolt to take

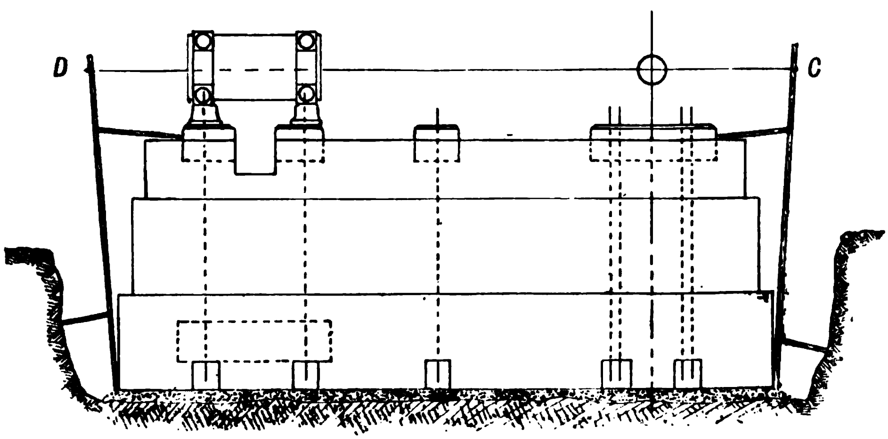


FIG. 12.—Longitudinal View of Loading, showing Centre Wire.

up the sag. If the work has been correctly done the wires will be in their proper positions when in the centres of the holes in the planks; but this is not likely, and the levels and horizontal distances are alternately adjusted until their positions are correct.

This final adjustment is rendered easier when the planks are firmly fixed and the holes bored at the proper level.

Levelling.—The main bearings are levelled with a spirit-level placed on the flywheel keyseat, or any parallel part of the shaft. The bearing to be raised should be lifted with the point of a crowbar resting on a piece of flat iron, wedges being driven only for final adjustment. These wedges are inserted at the front and back of the bearing, two at each end; folding wedges may be used should one not be thick enough.

The accuracy of the levelling may be checked by a plumb line suspended from a point above, so that it shall hang near the crank face. With the crank in its highest position make a mark in its face near the circumference, and measure from the mark to the plumb line. Now turn the shaft until the mark is in its lowest position and again measure to the line. If both measurements are identical, the shaft is level. It is immaterial how much the crank face is out of truth provided the measurements are made to the same point. Should there be any end play in the bearings, eliminate it by pushing the shaft hard over to the right or left each time a measurement is taken.

This plumbing is only necessary when the level cannot be relied on, and should be avoided if possible, as it is likely to interfere with the centre line.

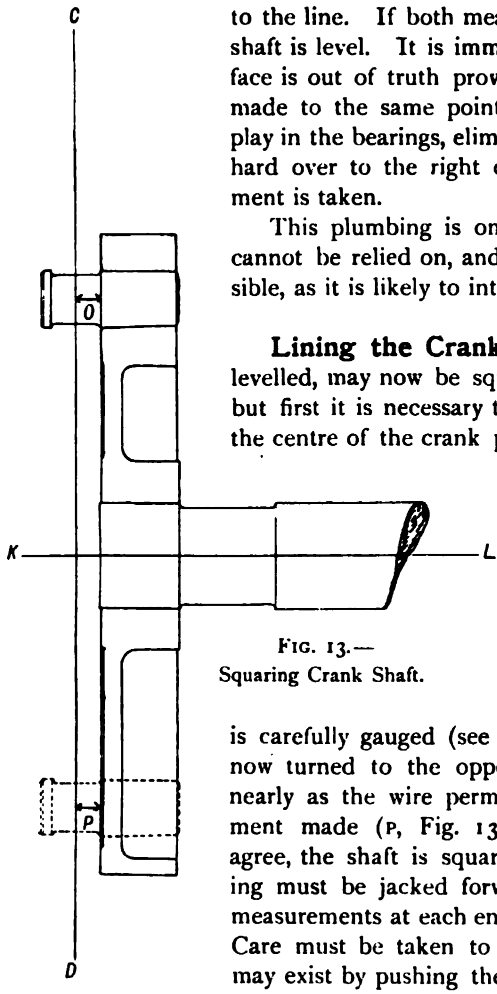


FIG. 13.—Squaring Crank Shaft.

Lining the Crank Shaft.—The shaft, being levelled, may now be squared with the centre line; but first it is necessary to see that the line intersects the centre of the crank pin bearing. Should it not do so, the crank must be adjusted on the shaft, or the whole shaft moved to the right or left. The crank being at one end of the stroke, the distance from the centre line to one side of the crank pin bearing is carefully gauged (see O, Fig. 13). The crank is now turned to the opposite end of the stroke, as nearly as the wire permits, and the same measurement made (P, Fig. 13). If these two measures agree, the shaft is square; if not, the opposite bearing must be jacked forward or backward until the measurements at each end of the stroke are identical. Care must be taken to eliminate any end play that may exist by pushing the shaft hard over to one side or the other. The shaft is now both level and square. Tighten the foundation bolts on the main bearings, and connect the guide trunks and cylinders.

Fixing Guides and Cylinders.—These are located by gauging from their interior machined surfaces to the centre wire, the best gauge for

the purpose being an ordinary piece of soft deal, about the size of a lead pencil, with a pin pushed into each end. Lift the cylinder by wedges inserted at the front and back, until the distance from the wire to the bottom of the stuffing box bore is the same as it is to the top. Adjust the back of the cylinder also on wedges until that end too is centred on the wire. Next adjust the cylinder horizontally, moving it to the right or left as required. Check the vertical and horizontal measurements alternately, as movement in one direction may disturb the other, and shifting the front end will alter the back.

Occasionally test the cylinders to see that one side is not higher than the other; this is done by a spirit-level placed on the valve box or any flat machined surface. The level may also be tried in the bore to guard against possible sag in the wire.

All these adjustments have to be gone over several times until the cylinder is in place, and the gauge, when placed in the bore at 3, 6, 9, or 12 o'clock, lightly touches the line when the free end is swept past it. In exactly the same way any other cylinders or air-pump barrels are aligned with the centre wire, the distance pieces being first inserted between them.

If the guides are bored out they may be centred, in the same way as the cylinders, by gauging from the machined surfaces. When planed there may be a slight difference between the top and bottom measurements, but this is immaterial, as it is allowed for in planing the cross-head and slippers. In any case both top and bottom guide surfaces must be parallel with the line.

Planed guides are adjusted to the centre line by their flats and edges, while a sheet-iron template is used should they be V section. The remaining foundation bolts may now be dropped into position and tightened with an ordinary spanner to a solid bearing: see that the rounded end only of the bolt projects above the nut, when half-a-dozen threads come through it shows slovenly work. Check all measurements again to make sure nothing has sprung or shifted during tightening.

Bedding the Frames.—The feet on which the engine rests may now be a quarter of an inch or so above the cap stones, and it is necessary to fill this space so that the feet bear evenly over their whole surface: this may be done in several ways.

When the interval is a quarter of an inch or less, lute around the outside with clay, block up the foundation bolt holes with waste, and lute or grout the joint with neat Portland cement.

When the space exceeds a quarter of an inch, use thicker cement mixed with an equal quantity of sand; or a rust joint may be made, but must not be caulked, only tamped into position with a piece of thin board. In both these operations men must work opposite each other, the space being first filled at the centre and finished at the outside. Alternative

plans are to fill with melted sulphur, or with parallel strips of hard wood; wedges must not be used, each slip is planed to fit the part of the opening it has to fill, and lightly tapped, not driven, into position.

Foundation Bolts.—When this joint has set, the bolts should be again screwed up, this time with a long-handled spanner, or one which has been lengthened by a piece of pipe slipped over its end; they will need a final screwing after the engine has worked a day or two. Nothing is gained by filling around the foundation bolts with concrete or cement, by reducing the size of the pipes through which these bolts pass, or by dropping them through the bed-plate and building around them. Such arrangements might be beneficial if the bolts were subject to any shearing strain, but they are not; all the strain is tensile; and no matter how carefully the work was laid out, the extra half-inch around the bolt may be of the greatest use in the final adjustments.

Two and a half inches square inside is the smallest size advisable for these pipes, and answers for engines up to 14-in. bore; from 14-in. to 24-in. bore 3-in. pipes may be used, and from 24-in. to 48-in., 4-in. pipes; while the 3-in. bolts of an 80-in. pumping engine will pass through 6 in. pipes.

All main parts of the engine being now correctly placed, the centre wires may be removed after a final checking of levels and measurements. It should be noted that the principles indicated are adapted to all classes of horizontal engines, and that the wires from which the work has been aligned are but reproductions of the centre lines laid down by the draughtsman when he began the design.

A horizontal engine mounted on a bed-plate presents even less difficulty, and alignment is secured in exactly the same way, by the path of the crank and the bore of the cylinder.

Assembling.—The pistons, after being thoroughly cleaned, may be placed in the cylinders; see that the spring rings are free to move and correctly set. The rods may be passed through the covers and joint rings and secured to the pistons, screwing hard up and staking over the last thread.

Fit on the cross-head and keep the cylinder covers in position with a couple of nuts. Now push the piston up against the front and back covers, marking in each direction the extreme travel of the slipper on the guide; these marks will denote the clearance remaining as wear takes place in the bearings.

The flywheel may now be placed in position; should it be in one piece a crank must be removed after its position on the shaft has been marked. Let the wheel rest on blocking in the pit while the upper part is supported by tackle or securely shored; work the shaft through, lower into its bearings, locate the wheel in its proper position and key up.

Wheels made in two or more pieces will be held together by bolts in the rim and bands shrunk around the hub; in this case assemble as before, the lower parts being blocked up in the pit.

Bolt the sections together, and enter the key a few inches to ensure the alignment of the keyways, as it may be impossible to move the wheel after the bands have shrunk. With the appliances usually found on a mine the bands cannot be heated after they are on the shaft; and if they will not pass over the cranks they must be heated and held over or around the shaft while the latter is passed through the wheel. Verify the position of the wheel on the shaft before shrinkage takes place. The bolts in the rim may now be removed and their shanks heated to a dull red before

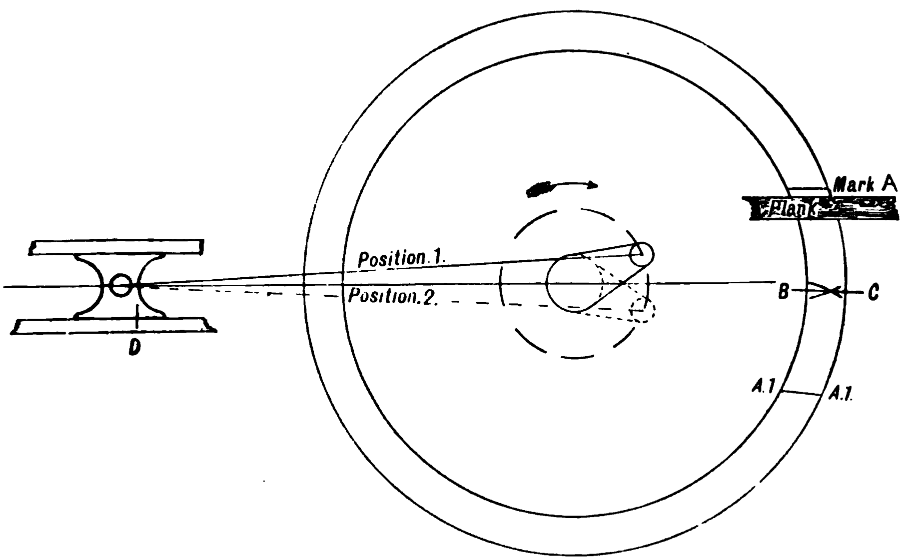


FIG. 14.—Placing Engine on Dead Centres.

being finally screwed up; to avoid distortion of the wheel alternate bolts from the right and left hand sides should be tightened, as in making a joint.

Finally, tighten the key, and see that any eccentrics or governor pulleys are in position before dropping the shaft back into its bearings. The connecting rods should now be put on.

Dead Centres.—There are, of course, many ways of setting an engine on its centres, but the following plan is so easy and so accurate that it should be more generally used. It applies equally to engines set horizontally, vertically, or at any angle; and when the marks have been made,

the connecting rods may be removed and the operation of valve setting performed by turning the shaft only.

1. At any convenient point in the circumference of the flywheel or belt pulley fix a piece of plank with top edge planed; the plank must be close to the wheel, but the latter must revolve freely without touching it.

2. Turn the engine round until it is near the end of the stroke, exact position quite immaterial; scribe a line across the edge of the guide and slipper, and another line from the top edge of the plank on to the surface of the wheel.

3. Turn the engine in the same direction as before until the crank has passed the dead centre, and the marks on guide and slipper again coincide. Scribe from the plank to the wheel, as before.

4. Bisect the distance between the two scribed marks on the wheel, and turn the shaft until the point of bisection is opposite the scriber on the plank. The engine is now on dead centre.

This is repeated at the opposite end of the stroke, and the connecting rods can be taken off, since the engine will always be on centre when the points of bisection correspond with the scriber point. Both ends of the stroke may be scribed from the same plank surface.

Valve-Setting.—Among the advantages claimed for Corliss valves are a sharper cut-off, less clearance, less friction, less condensation owing to separate valves for steam and exhaust, and better drainage of the cylinder. They cannot, however, be set in the same way as slide valves, since, when in position, neither their leading edges nor the ports they cover are visible. Before inserting each valve in its box, place a straight-edge along its leading edge, and scribe a continuation of that line on its outer surface. The edges of the steam and exhaust ports must be marked in the same way.

Fasten a weight to each end of a line, and hang it over, or suspend it from, the wrist pin on which the eccentric rod works. Measure from the front part of the line to the front exhaust pin, and from the back part of the line to the back exhaust pin, turning the wrist plate until these distances are equal. This plate is now in the centre of its stroke, and if the steam valves are coupled up by their rods the marks made on their faces should indicate equal lap over each port. Should these laps not be equal, make sure that the wrist plate has not altered its position before adjusting the lengths of the valve rods. On a 25-in. cylinder the steam valves will have about five-sixteenths of an inch lap, the exhaust valves half this amount.

Having keyed up the eccentric, bolt on the strap and rod, and place the free end of the rod on a piece of plank fixed, as nearly as possible, level with the eccentric pin in the wrist plate. Scribe a mark on the eye or

joint at the end of the rod, turn the engine round and mark on the plank the two extreme limits of the path travelled by this scribed mark. The distance so marked is the stroke of the eccentric; bisect it, and bring the mark on the rod to coincide with the point of bisection; the eccentric is now in the centre of its stroke. In this position the eye of the rod should engage with its pin on the wrist plate; if not, see that the plate has not moved from its central position before lengthening or shortening the rod to make it engage with the pin. The lead of the valves will be equal if the eccentric is correctly placed in relation to the crank; it may be checked by turning the engine slowly round, and marking on the guides the position of the cross-head at the moment the valves trip. The trip, or release, of both valves should take place when the piston is the same distance from the end of its stroke. If necessary, it may be adjusted by altering the length of one of the valve rods, equal lead being even more important than equal lap. The exhaust valves are set in the same way, and the dash pots connected after having ascertained that the length of their rods will allow sufficient clearance at both ends of their strokes.

Setting Slide Valves.—Before leaving this part of the subject it may be advisable to describe briefly the setting of ordinary slide valves, such as are used in a pair of winding engines, fitted with reversing gear. Although differing entirely in shape from the Corliss, the slide valve performs the same duty, that is to say, it determines the points at which steam is admitted to, cut off from and released from the cylinder, with relation to the position of the piston in its stroke.

The exact point of steam admission to the cylinder depends on the lead of the valve, lead being the width of steam port uncovered by the valve when the crank is on dead centre.

The point in the piston stroke at which steam is cut off depends mostly on the lap; in other words, the amount by which the exterior of the valve overlaps the steam ports.

The amount of lap is fixed in any particular engine, since it depends on the relative dimensions of the valve and ports; the lead is not fixed by any proportion of parts, but depends on the angular advance of the eccentric in front of the crank.

Yet the two, lap and lead, are so intimately connected that neither can be altered without disarranging the other. If lap is taken off a valve, the eccentric must be placed further ahead of the crank to maintain the same lead; and should the eccentric and amount of lead be altered, the point of exhaust cannot remain unchanged. The stroke of the slide valve in any ordinary engine is equal to twice the width of one steam port added to the amount of lap.

The angle at which the eccentric stands in advance of the crank is equal to 90° plus an advance equal to the lap and lead of the valve; if

these two factors did not exist, the amount of advance would be exactly a quarter of a revolution.

In practice, the position of the eccentric is fixed by that of its keyway on the shaft, and this is usually cut before the engine leaves the maker's hands. In case this keyway has not been cut, its position may be determined by trial, or by a diagram, preferably drawn full size, on the lines indicated in Fig. 15.

Let M N be a line joining the centre of the shaft to that of the crank pin; at any point near one end of it erect a perpendicular S T, and from the same point draw a circle B C D equal to the travel of the slide valve, and a circle E F G representing the shaft. On the side of S T remote from the crank pin draw the line A A parallel to S T, and distant from it the amount of lap and lead of the slide valve. This line intersects the circle

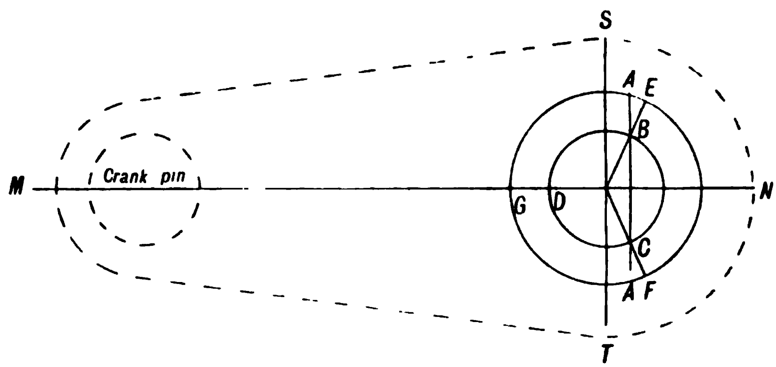


FIG. 15.—Diagram for finding Position of Eccentric Keyways.

B C D at the points B and C. Draw lines joining these points to the centre of the circle; extend these lines to the circle E F G, and the points of intersection E and F will be the centres of the keyways for the forward and backward eccentrics respectively.

It is somewhat difficult to transfer to the shaft the positions determined by the diagram, and on the whole, perhaps the ordinary method of trial and error is preferable; the procedure is as follows:—

First, by the help of a square placed against the cylinder face, scribe lines on the valve chest so that the position of the steam ports may be known when they are covered by the valve. Place the valve on the cylinder face; connect it to its spindle, lost motion between valve and spindle being carefully avoided; connect spindle and slot link together. Slide the eccentric along the shaft until the end of its rod engages easily with the slot link; connect, and adjust the reversing lever until the rod end is level with the valve spindle. Revolve the eccentric in either

direction, marking the extreme travel of the valve towards the front of the valve chest, and measure the amount by which it overlaps the steam port; let us assume this to be $2\frac{3}{4}$ in.

Again revolving the eccentric, mark the limit of valve travel at the opposite end of the stroke and measure the lap over the port; here it may be only 2 in. Therefore the distance between the centre of the eccentric and the centre of the valve travel is too great or too little by $\frac{3}{4}$ inch, and either the rod or the valve spindle must be altered by an amount equal to half the difference in the measurements. When the excess is at the crank end the rod must be lengthened; should the excess be at the opposite end the rod requires shortening. The length of the four eccentric rods may all be certified in this manner, and it is advisable to do it whether the position of the eccentrics on the shaft is known or not. By doing so, one possible cause of error—difference in length of rods—is removed; and it only remains to place the eccentrics on the shaft in correct relation to the crank.

The engine must first be centred. The operation has already been described, and illustrated in Fig. 14, in which D is the mark scribed on cross-head and guides, and A the mark made on the rim of the wheel with the crank in position 1. The engine being turned in the direction indicated by the arrow, passes the dead centre, and the marks at D again coincide on the return stroke; the crank is now in position 2, and mark A has gone round to A 1. A fresh mark is now made at A, the distance between A and A 1 bisected at B O; the engine is turned until B O coincides with A, and is then on its dead centre.

With the engine in this position throw the reversing lever alternately into forward and backward position, adjusting and temporarily fixing the eccentrics on the shaft when the steam port shows the desired amount of lead. Turn the engine to the opposite centre, and note if the lead is equal, shifting the eccentric, if necessary, by an amount equal to half the difference. The position of each eccentric is found in this way; they must stand on the shaft so that their rods work in pairs, the two attached to the upper or lower ends of the slot links being either for forward or backward motion of the engine. The keyseats may now be scribed on the shaft from the ways cut in the eccentrics.

The reversing sector is notched by raising or lowering the links until a pair of rods are opposite the valve spindle joint; rotate the engine to see that there is sufficient clearance at the ends of the links, and mark the position of the reversing lever on the sector. The process is repeated with the other pair of rods engaged. Midway between these extreme marks on the sector is the neutral point, and the interval on each side may be subdivided as desired.

When nuts are used to secure the slide valve to the spindle, they should be tightened hard against each other, but must not bind the

valve. The latter should move freely, but without play, and be free to adjust itself to the cylinder face.

Engines in which frequent reversal of motion is not required are often fitted with adjustable expansion valves on the backs of the main slides. To set these, the screwed spindle is entered into each half of the expansion valve at the same time, and they are brought close together by turning the spindle. It is now only necessary to see that when the expansion eccentric is in the middle of its stroke, the expansion valves stand in the middle of the travel of the main slide valves.

Jointing Up.—The ports and steam ways being clean and free from sand, the cylinder and valve covers may be jointed up; rings of brown or cartridge paper soaked in oil answer well for this purpose. Steam connections are made and pipes lagged, water and overflow laid on in the case of a condensing engine; drain pipes and connections should fit tightly, be well screwed home, and the outlet led outside the engine-house or to the condenser. This recalls a particular engine which proved very wasteful in steam, whose valves and piston had been repeatedly overhauled without effecting any improvement; finally it was condemned and about to be replaced. On removing the cylinder the cause came to light; the mechanic who erected it had joined the drain pipes from opposite ends of the cylinder to a common Tee, *outside* which he had placed the only drain cock. The consequence was that the two ends of the cylinder were always connected by an open three-quarter pipe, and the arrangement, being hidden by a deep box bed and covered by the cylinder, escaped detection for many months.

The same presiding genius also erected a small winding engine with valves and eccentrics so mixed that one half of the engine wanted to hoist when the other half wished to lower.

Before leaving the subject of engine erection, allusions must be made to two variations which may occur and are frequently not as skilfully carried out as they might be.

1. When an additional side is to be connected to an already existing engine in order to make a pair:—In which case the new part must be level, square, and parallel with the old engine.

The centre line is obtained from the path of the crank pin, as already described; should the new crank not be available it may be represented by a timber clamp bolted to the end of the crank shaft. Hang a plumb line so that it shall pass the end of the shaft, and adjust it until the distance from the line to the shaft is the same as from the shaft to the centre of the crank pin on the side of the engine already in position. This line now represents the centre of the future crank pin; drive a nail into the face of the timber clamp, near its outer end, until the head of the nail just touches the line. No matter how rough or out of truth the clamp may be, the head

of this nail now lies in the plane of the centre of the crank pin, and at each revolution describes a circle truly at right angles to the axis of the shaft. A wire placed level with the centre of the shaft, and touched twice by the nail each time the shaft makes a revolution, will be the correct centre of the new engine; and from it the loading may be laid out and engine centred.

2. In cases of engine extension or conversion it is sometimes necessary to add a horizontal cylinder or air-pump barrel in line with the existing engine. The new cylinder cannot be centred from anything so liable to deflection as an extended piston rod; a wire must be reeved completely through the engine as already described.

If the engine is placed on centre and the wire made fast to the middle of the crank pin bearing it will be very near its true position, and can be certified by gauging from the stuffing-box; do not gauge from the gland, which is subject to wear, but from the counterbore of the stuffing-box itself. The opposite end of the line is centred by gauging from the counterbore of the cylinder already in position. Levels may be checked by a straight-edge held truly on the bore of the smaller cylinder; gauge the difference between the staff and the bore of the larger cylinder, and see that this distance is everywhere half the difference in diameter between the two cylinders.

CHAPTER IV.

BOILERS.

Requirements—Power of Boilers—Vertical Boilers—Cochran Boilers, Particulars of—Cornish and Lancashire Patterns—Setting and Placing in Position—Multitubular—Water-tube—Babcock & Wilcox Boilers.

THE duty of the boiler is to evaporate water economically; and since it, not the engine, is the real generator of power, the pattern installed on any mine should be carefully chosen with a view to prevailing local conditions. Among the factors which influence this selection the following may be mentioned as of most importance.

1. The probable permanency of the work; types requiring masonry settings being unsuited for temporary purposes.
2. Transport, its cost and facilities; a factor affecting the type as well as governing the weight limit of each unit.
3. The quality of the fuel and feed water; the former often determining whether the boiler shall be internally or externally fired, while on the latter depends the facilities demanded for cleaning.
4. The quality of labour available, some boilers being safer than others in unskilled hands.
5. The evaporative power required, or the grate and heating surface.
6. The demand for steam, whether regular or irregular.

Vertical Boilers.—In the early stages of prospecting and development, and for isolated work such as diamond drilling, the vertical boiler is very useful; owing to the entire absence of masonry setting it is easily and cheaply erected, in fact the operation may be performed in a few hours. On account of their cylindrical shape, they are easily transported over rough ground, by rolling on skids, after the mountings have been taken off; at the proposed site no preparation is needed, except a hard and level bed on which the boiler may stand.

Among the disadvantages common to the type is the small size of the internal firebox; on this account wood fuel has to be cut to less than standard sizes, at additional cost. Being seldom jacketed or protected in any way from the weather, they cannot be considered economical; many tests made under ordinary working conditions, when supplying steam to hori-

zontal non-condensing engines, show a consumption of from 9 to 12 lbs. of hard wood per 1 H.P. per hour.

Boilers are rated by their evaporative power. The term "Horse-Power" is inapplicable, since the duty of the boiler is completed when the water has been evaporated with a minimum expenditure of fuel. The power afterwards obtained from the evaporated water depends on the efficiency of the motor; some engines yield a horse-power on 12 lbs. of steam per hour, while many direct-acting pumps require 300 lbs. Non-condensing engines are averaged at a consumption of 30 lbs. of feed water per hour, and the evaporation of this quantity is known as a boiler horse-power. In vertical boilers this will be effected by 4 to 5 lbs. of coal, requiring a quarter of a square foot of grate surface for its consumption.

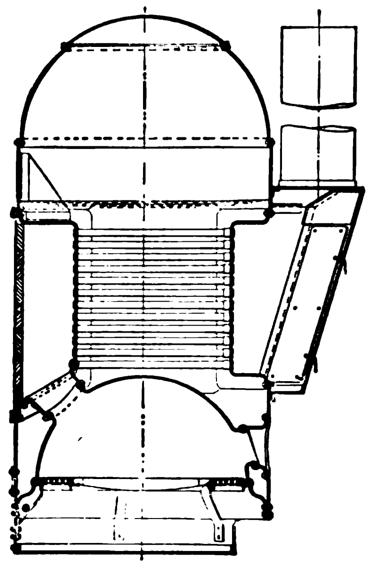


FIG. 16.—
Vertical Section, Cochran Boiler.

In selecting a vertical boiler, one of the multitubular type will probably be preferred, as affording greater heating surface and therefore greater evaporative power for a given weight. This form is safer than many others in inexperienced hands, since shortness of water can only damage a few small tubes, instead of burning the crown of the furnace. Owing to the rapid circulation, the interior keeps free from scale, even when impure feed water is used; the impurities are deposited in the lowest parts of the boiler, and being below the heat of the furnace, do not harden, and may be cleaned out as soft sludge through doors provided for the purpose.

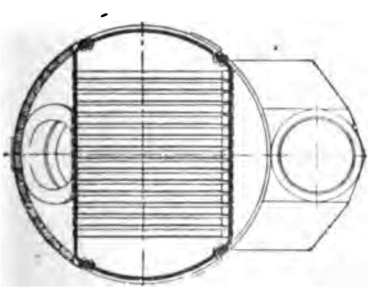


FIG. 17.—
Sectional Plan, Cochran Boiler.

Among the different patterns of multitubular vertical boiler the Cochran is one of the most popular and will be found on almost every goldfield; here the compactness and portability of the ordinary boiler are combined with special internal accessibility and evaporative power. The tubes run horizontally through the shell, from side to side, and one of the features fully appreciated on

mines is, that by opening the doors at each side, the tube-plates and tubes are fully exposed. The crown of the furnace is pressed to hemispherical shape from a single plate, the flanged openings for the fire door and uptake being pressed from the same sheet. By adopting this method of manufacture all interior furnace seams are removed from direct contact with the fire.

When required for merely temporary use the boiler is placed upright on the ground ; if for more permanent work, extending over some months, it is advisable to build a masonry foundation raising the foot of the boiler about 6 in. above the level of the ground, and protecting it from corrosion.

PARTICULARS OF COCHRAN BOILERS.

Diam. in Ft.	Height in Ft.	Grate Surface in Sq. Ft.	Heating Surface in Sq. Ft.	Weight in Cwts.	Table I.				Table II.			
					Coal.	Water Evaporated.			Coal.	Water Evaporated.		
					Lbs. per Hour.	Per Lb. of Coal.	Per Hour.	I.H.P.	Lbs. per Hour.	Per Lb. of Coal.	Per Hour.	I.H.P.
3	6¾	4.6	60	25	80	5.0	400	13	48	6.25	300	10
3¼	7½	5.5	80	28	100	5.0	500	16	60	6.25	375	12
3¾	8½	7.5	100	39	144	5.0	720	24	86	6.25	540	18
4	9	8.5	120	50	174	5.0	870	29	104	6.25	652	22
4¼	9½	9.3	140	58	192	5.2	999	33	115	6.5	749	24
4½	10	9.7	160	63	202	5.42	1,094	36	121	6.77	820	27
4¾	10¼	11.8	200	70	256	5.51	1,409	46	153	6.88	1,056	35
5	10¾	12.6	220	78	275	5.6	1,540	51	165	7.0	1,155	38
5¼	11¾	13.9	250	90	313	5.6	1,753	58	187	7.0	1,314	43
5½	12¼	15.9	300	102	357	5.8	2,070	69	214	7.25	1,552	51
5¾	13	17.5	350	112	405	5.9	2,390	79	243	7.37	1,792	60
6	13½	18.9	350	119	442	5.7	2,519	83	265	7.12	1,889	63
6	14	18.9	400	129	442	6.0	2,671	89	265	7.56	2,003	66
6½	14	21.5	450	145	511	6.0	3,069	100	306	7.5	2,301	77
6½	14½	21.5	500	156	511	6.3	3,224	107	306	7.87	2,418	80
7	14	24.8	500	168	597	5.9	3,525	113	358	7.37	2,643	88
7	15	24.8	600	183	597	6.45	3,849	128	358	8.06	2,886	96
7½	16¼	31.5	730	210	766	6.36	4,878	162	459	7.95	3,658	120
8	16½	35.0	850	240	858	6.5	5,582	186	514	8.12	4,186	139
8	17	35.0	1,000	280	858	7.0	6,074	202	514	8.75	4,555	150

In the above table the smallest boilers are credited with a consumption of 16 lbs. of coal per square foot of grate and an evaporation of 5 lbs. of water per pound of coal, allowances gradually increasing until, in the larger sizes, 24 lbs. of coal are burned per foot of grate and 6½ lbs. of water evaporated by each pound of coal. With good fuel and skilled attendance the results in Table I. are obtainable, and may be regarded as the maximum for the size of boiler in question.

Table II. assumes the boilers to be worked at 75 per cent. of their maximum evaporative capacity, the coal consumption 60 per cent. of the

maximum, and the evaporation per pound of coal 25 per cent. higher than when the boiler is forced to its fullest extent. The indicated horse-power column is based on a consumption of 30 lbs. of water per horse-power per hour. Deductions must be made from these tables should the coal used not be equal to average Welsh, and at least 50 per cent. should be taken off when wood is burnt.

Cornish and Lancashire Boilers.—These types, owing to the amount of masonry required in their settings, are suitable only for work of a more permanent nature; being accessible and easily cleaned, they suffer less than other varieties from impure feed water. Owing to the ample steam and water space provided, constant attention is not required from the fireman; for the same reason they are well adapted to intermittent work such as hoisting.

Although economical generators of power when worked well within their capacity, these types steam slowly on account of the quantity of water contained, and their slow circulation; they are therefore heavy and bulky for a given power, considerations which carry weight when transport is expensive. The internal flues are possible sources of danger, being the first parts bared in case of shortness of water; and in most foreign countries repairs are not easily effected.

In spite of their considerable weight these boilers, when made water-tight by closing all openings, may be lowered overboard from vessels, floated ashore, towed up rivers, and rolled through miles of trackless country into apparently inaccessible places.

Setting.—As those who design the general plan of an installation are probably not acquainted with local conditions, the relative position of boilers and engine as planned need not be too strictly followed, in fact may often be altered to advantage. The objects in view are: to place boilers and engines close together but without crowding, to allow extension of power plant, provide for delivery of fuel, and storage of both fuel and water supplies. Batteries of boilers are often hemmed in by an engine on each side, an arrangement which does not lend itself to extension; true, larger boilers may be substituted for those in use, but this means temporary interference with the work of the mine, while, to guard against break-down, it is safer to multiply the units than to enlarge them.

In most cases the boilers will stand either parallel with or at right angles to the engines, and the settings may be laid out from the original datum line; a line stretched over the engine, plumb with the centre of the crank pin at one end and with the centre of the cylinder at the other, will be sufficiently accurate. A parallel line is now required, distant from the centre of the steam opening on the cylinder an amount equal to the total amount of the elbows, bends and set-offs in the steam pipe; it may lie on

either side of the steam opening, according to the direction taken by the piping. This line is produced across the boiler settings, and from it the centres of the steam openings on the boilers may be laid off by allowing for length of branch pipes and set-off on stop valves. Should the boilers be at right angles to the engine, the line will be squared with the datum line, the same precautions being observed regarding set-offs in the piping. See E, F, Fig. 19.

In either case all the boiler settings will be laid off from this line, which should be permanently marked by posts and nails on each side of the site. The distance of each boiler from the steam opening on the cylinder is now laid off on the line, and the foundation pit pegged off. The whole of the

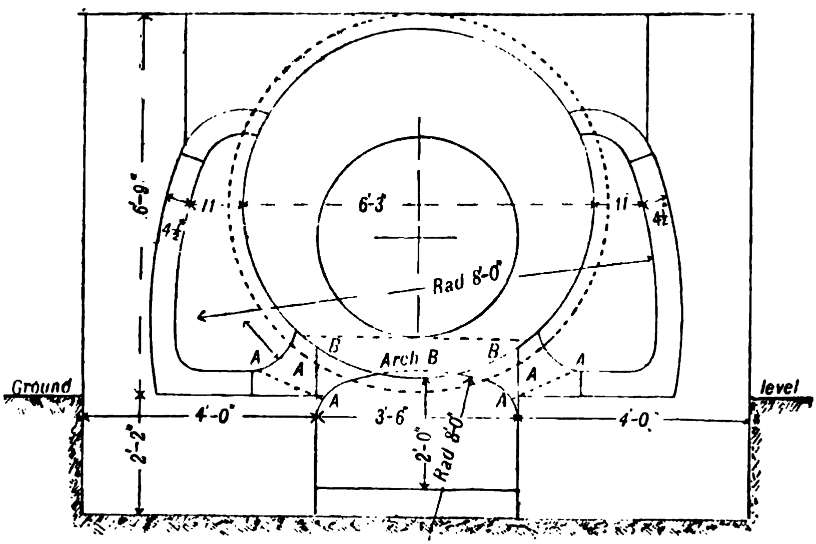


FIG. 18.—Horizontal Section through Cornish Boiler and Setting.

ground within the pegs is excavated to a depth of about 2½ ft., and the bottom of the pit paved; the distance from the engine to the centre of each boiler is measured off, and the centre flues and masonry on each side are marked off, the lines being all parallel with the centre line.

The masonry on each side of the centre flues is now carried up to the height required for the seating bricks; in Fig. 18 this corresponds with the ground level. As the fire is within the boiler, this part of the setting is of ordinary rubble masonry, bricks being only used for the back arch, seating, and flue covering. Building stones which contain lime, or enclosed globules of water (such as quartz), should be avoided.

Placing Boilers.—If the ground permits, it is easier to roll the boilers on to their seatings from one side than to drag them on endways; it will

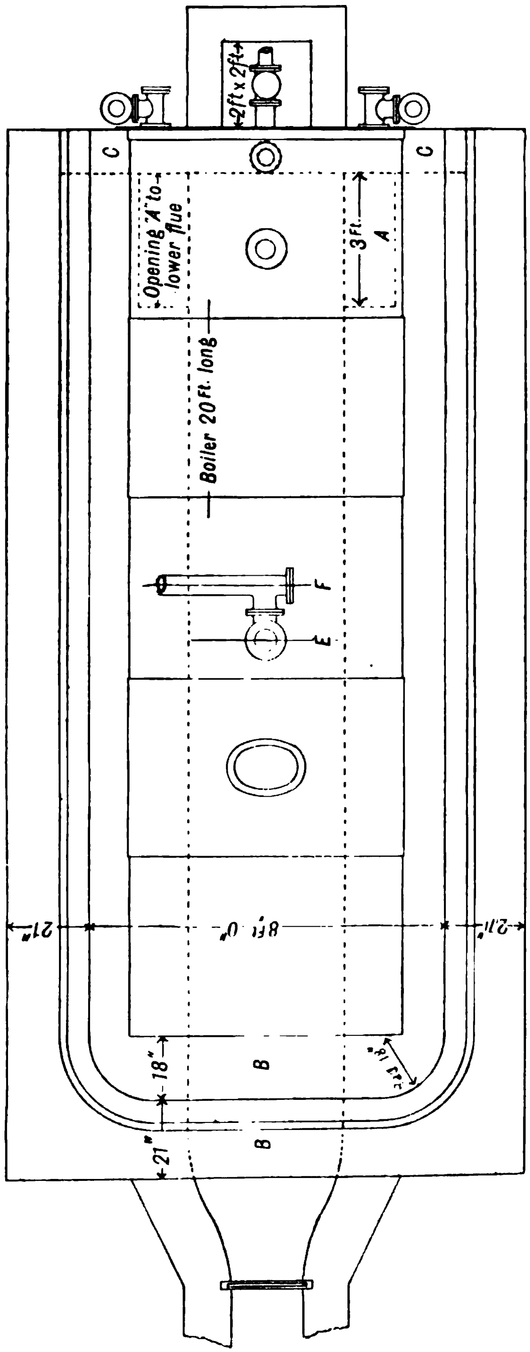


FIG. 19.—Plan of Cornish Boiler and Setting.

also save time if the respective ends of the boilers face the right way before they are unloaded from the waggons. In unloading, skids are placed on each wheel, distanced by a spreader, their ends strutted and their feet let into the ground. A chain is now made fast to the top of the boiler, its rear end being secured to a tackle and anchorage; it is slacked out as the boiler rolls down the skids—an operation the reverse of parbuckling.

Other skids are placed on the ground to receive the boiler; these should be of such thickness that the mountings clear the ground. On the last skids, those spanning the flues, should be laid a few feet of flat iron, well greased; on these irons the boiler may be turned if necessary, or jacked forward or backward to meet the centre line. When approximately correctly placed, the skids are withdrawn and the boiler rested on blocking in the flue; this blocking being also covered with greased flat iron.

A Cornish boiler is placed vertically by plumbing from its centre to the centre of the flue; a Lancashire, by a level placed across the flues. Both may be checked by a level placed on the mountings; the plumb line from the boiler centre should hang in the centre of the flue. Jack longitudinally as required until the steam opening is the right distance from the engine line. See E and F, Fig. 19. Levels may be checked by luting up the ends of the flue with clay and filling within with water to the depth of an inch or two. In boilers exceeding 20 ft. in length it is customary to allow a drop of three-quarters of an inch towards the blow-off cock, but this is optional. The boiler being correctly placed, longitudinally, transversely, and vertically, the seating bricks may be built in and the masonry finished level with the bottoms of the side flues.

There is no recognised rule as to whether the gases, on leaving the centre flue, should first traverse the side or the lower flues. At the first glance it would appear correct to apply the heat at the lowest point, but the area here is only half that of the side flues. In practice it makes no appreciable difference in the fuel consumption, and is generally more convenient to use the side flues first, letting the gases leave the boiler by the bottom. Nothing is gained by contracting the flue area and hurrying the heated gases up the chimney, while flues of ample area are easily inspected and not so readily choked with ashes when wood is burned. When the side flues are covered with arched bricks, their walls are built vertically. Those shown in section in Fig. 18 are easier of access and are built on timber centering, which is left in position and burned out. In each case the side flues should extend right out to the boiler front, so that the temporary stopping may be removed when the boiler is cleaned.

Before the side flues are commenced, the timber blocking is withdrawn. This is done, without injuring the masonry, by placing a jack at each end of the boiler, one to take the weight while the other lifts for withdrawal of the blocking. Sprags must be kept tight to the boiler sides that it may not roll out of position.

The seating bricks are omitted for a few feet on each side at the front end to afford communication between side and bottom flues. See A, Figs. 18 and 19. When the side and back flues are finished, the side and end walls are carried up a few inches above the top of the boiler, so that the whole of the top may be filled in with some non-conducting substance, such as sawdust, ashes, or sand.

The firing floor should be well below the boiler front, so that the shell may not be corroded by damp ashes; wood ashes being especially dangerous in this respect. Finally, the damper frames are built in and flue connected with the chimney. All masonry work about a boiler should be of the best quality, as infiltration of cold air through the setting is very detrimental to the performance of the boiler. For bridges and any parts exposed to intense heat, a mixture of clay wash and finely sifted wood ashes stands better than mortar made with lime.

When these boilers are to be placed in inexperienced hands, they are sometimes fired externally from below, the gases returning through the central flue and passing to the chimney by the sides. After the mountings are on and boiler filled, a small fire should be kept going for a few days to warm the water and dry the masonry slowly.

	Size in Feet.	Heating Surface.	Grate Area.	Evaporation.
Lancashire . . .	30 by 8	1,070	39	5,350
Lancashire . . .	30 ,, 7½	1,000	36	5,000
Lancashire . . .	28 ,, 7	850	33	4,200
Lancashire . . .	26 ,, 6½	740	30	3,720
Cornish . . .	24 ,, 7	580	27	2,900
Cornish . . .	22 ,, 6½	497	22	2,480
Cornish . . .	20 ,, 6	409	15	2,040
Cornish . . .	18 ,, 5½	340	12	1,700

The **Multitubular Boiler** consists of a cylindrical shell fitted with a tube plate at each end to receive the horizontal tubes which pass longitudinally through it. These tubes are generally 3 in. in diameter and vary in number with the size of the boiler, sixty being the average number. Through them the gases pass on their way to the uptake.

As with all externally fired boilers, the large furnace is particularly suited to wood fuel; while the fire, being entirely below the shell, is in the safest possible position in case of shortness of water. The small diameter of the shell is in itself a factor of safety when high pressures are required, for the ample heating surface and rapid circulation assist in keeping down the overall dimensions. A multitubular boiler, 4 ft. diameter by 14 ft. long, has one and a half times the evaporative power of a Lancashire boiler of double these dimensions. Hence it is small and light for a given evapora-

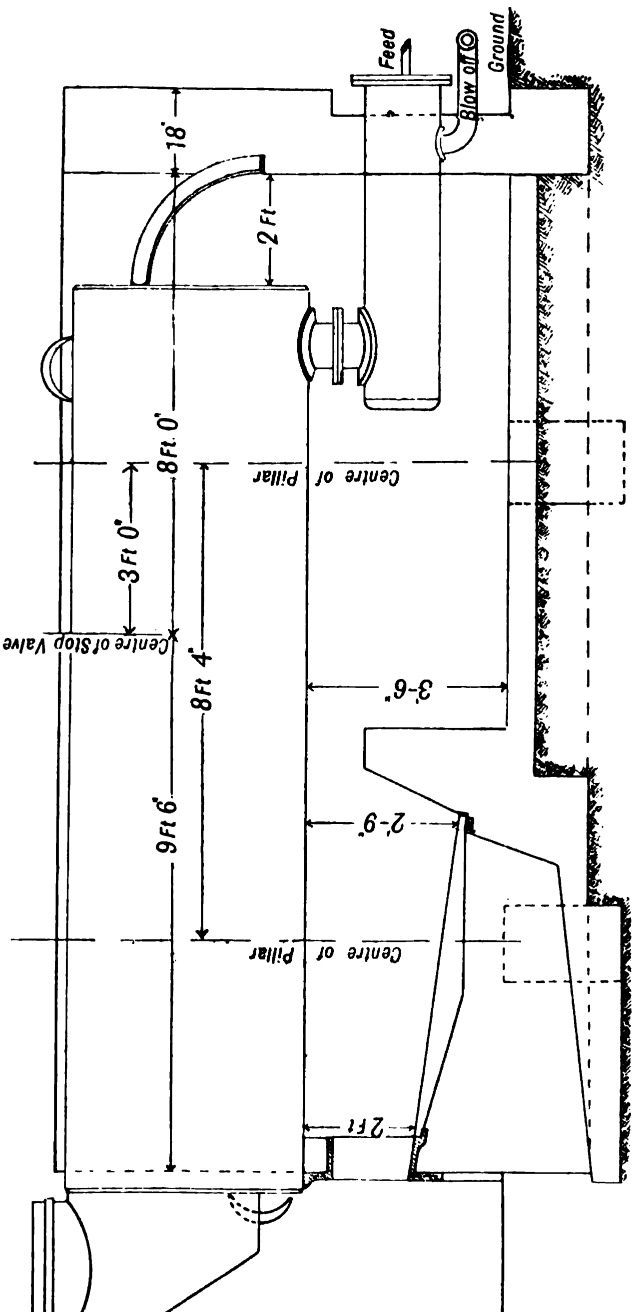


Fig. 20.—Multitubular Boiler. Longitudinal Section.

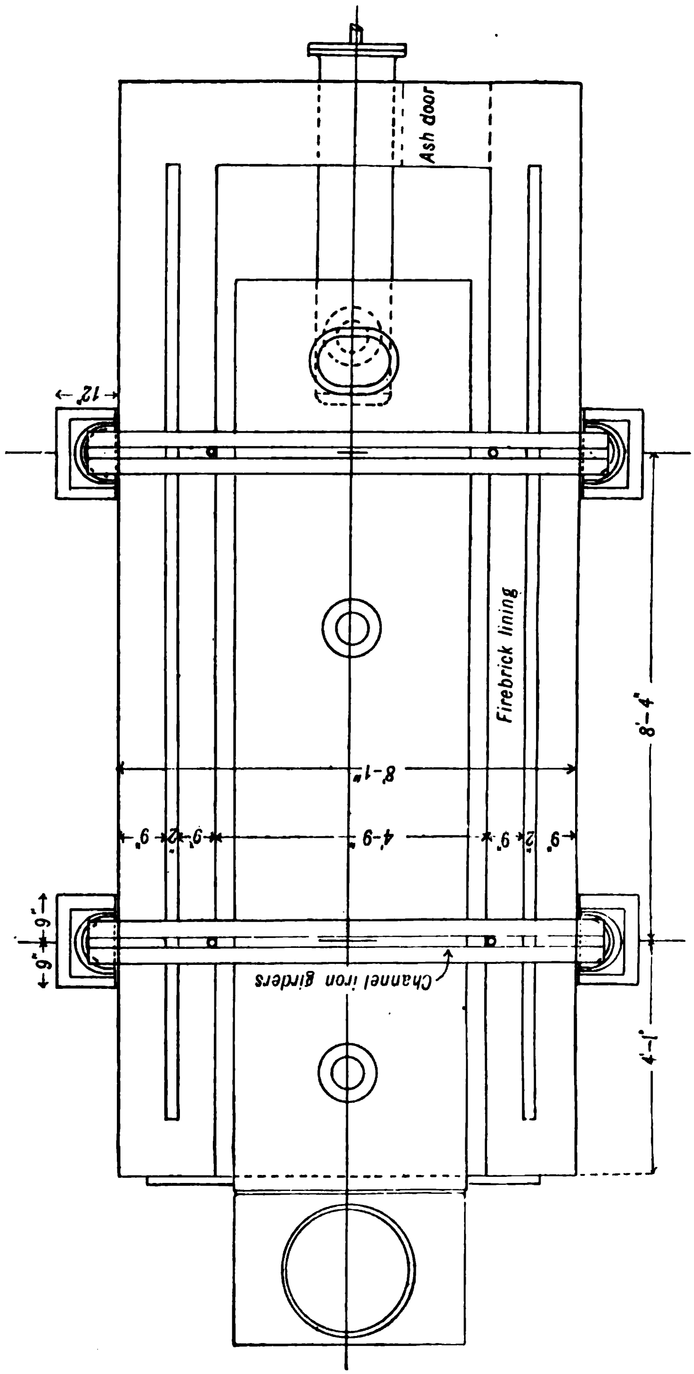


FIG. 21.—Multitubular Boiler Front. Sectional Plan.

tive power, and in the various considerations of transport, safety, and ease of repair, fully meets the requirements of mining usage.

Boilers of this type were formerly supported by lugs at the sides resting on the furnace walls. It is, however, a much better plan to suspend them independently of the setting. For this purpose two columns are placed on each side of the masonry, and the boiler hung from bolts resting on the girders connecting the pairs of columns. Fig. 20 illustrates both methods;

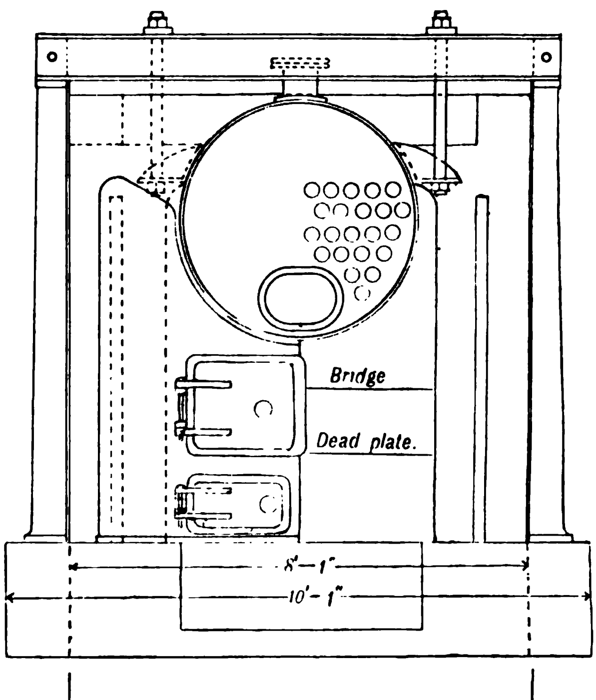


FIG. 22.—Multitubular Boiler.
Half Section.

the lugs were originally intended to rest on the masonry, but have been bored to receive the suspension bolts. Wrought-iron angle plates are generally used, as lugs project and are in the way while the boiler is being brought into position.

The erection and setting are illustrated in Figs. 20, 21, and 22. In laying out the setting, the four concrete piers on which the columns rest are first located. Their positions are found from the steam pipe line as before, allowance being made for the distance between the steam pipe

opening and the nearest pillar. In Fig. 20 this is 3 ft. The boiler is now rolled into position, jacked up the required height, and suspended from the cross girders, being levelled by adjusting the bolts. If desired, all steam and other connections may be made before the masonry is begun; the latter being marked off by plumbing from the boiler.

As it is directly exposed to the fire, the setting is usually of brick, the furnace being lined with firebrick set in fireclay or in a luting of clay wash thickened with sifted wood ashes. When wood is burnt, the wear on furnace linings is severe, and it is advisable to build them separately from the outer wall, leaving an air space of 2 in. between them.

Another very necessary precaution, where wood is used, is to allow ample depth to the ash pit, and so prevent the bars from being burnt and warped by accumulations of ashes.

The smoke stack is always of wrought iron, and rests directly on the uptake; or the uptake of two boilers may be joined by a breeching supporting a common chimney. When more than two boilers are used, they are either joined in pairs or connected to a horizontal flue leading to a chimney common to all. Dampers are provided in the flue to shut off any boiler not required. A cast-iron front-plate carries the fire and ash-pit doors, besides supporting the dead-plate and firebars. This plate is secured by bolts passing through the air spaces to the back of the boiler and serving to tie the setting together longitudinally.

MULTITUBULAR BOILERS.

Size in Feet.	Heating Surface.	Grate Area.	Evaporation.	Weight in Tons.
14 by 4	640	19	1,570	9¼
16 ,, 4½	790	24	1,930	11½
16 ,, 5	1,140	32	2,560	13¼
16 ,, 5½	1,480	35	2,800	14¼
16 ,, 6	1,900	45	3,600	20½

Smoke stacks are not included in the above table.

Water-tube Boilers.—In this class the water lies within the small tubes, not around them, each boiler consisting of several rows of tubes placed above the furnace and in connection with an overhead drum containing steam and water. As a class they possess all the advantages of the multitubular type and are more easily transported, in fact the light parts of which the smaller sizes are composed can be carried wherever it is possible for man to go. They may be left in inexperienced hands with less risk than the shell forms, as owing to the small diameter of the

tubes, serious damage is almost impossible; this is a matter of some importance in countries where the firemen always sleep when on night duty. The thickness of metal between the fire and water is much less than in shell boilers; they steam quickly, can be forced if necessary, and are easily repaired. Although the reserve of water is not large, the boiler responds quickly to demands made upon it; this is due to the rapid circulation, all the water being thoroughly heated and in a condition to be quickly converted into steam. The smaller sizes are furnished with a housing of cast-iron plates; in larger boilers the necessary brickwork often adds considerably to the weight and cost of transport.

Some of the earlier types were, unfortunately, not suited to foreign

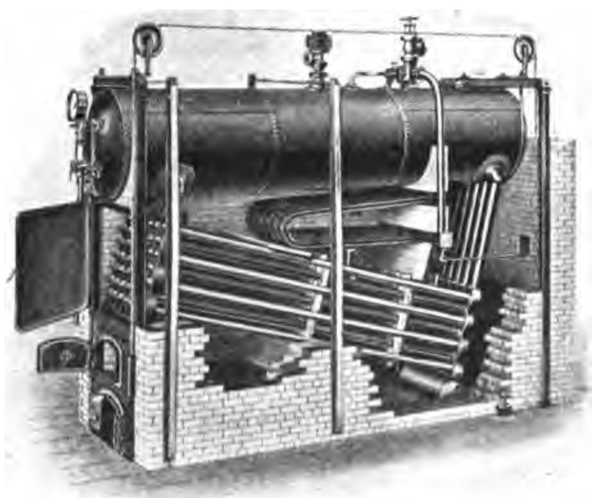


FIG 23.—Babcock & Wilcox Boiler, with Longitudinal Superheater.

requirements. The junction pieces were screwed on the tubes, and if a tube was burned, the junctions at each end were often sacrificed; the tightness of the joints depended too largely on packing material; and the baffle plates were so insecurely fastened that they were often displaced, allowing the gases to pass freely up the chimney without having first circulated around the tubes. They were also unnecessarily sectionalised; and the gain in portability thus obtained was outweighed by the inconvenience of an excessive number of joints. These defects resulted in an undesirable reputation, but the type has been gradually improved, and the modern development is shown in the form made by Messrs Babcock & Wilcox, who have done much to eliminate the defects of the earlier designs.

The Babcock & Wilcox boiler is composed of wrought-steel tubes placed in an inclined position, and connected to each other and to a horizontal steam and water drum by vertical passages at each end. A mud drum is connected at the rear to the lowest point in the boiler. The steel end connections are in one piece for each vertical row of tubes, and are of such form that the tubes are "staggered" or arranged in zigzag rows, to more thoroughly intercept the hot gases. All the holes are bored

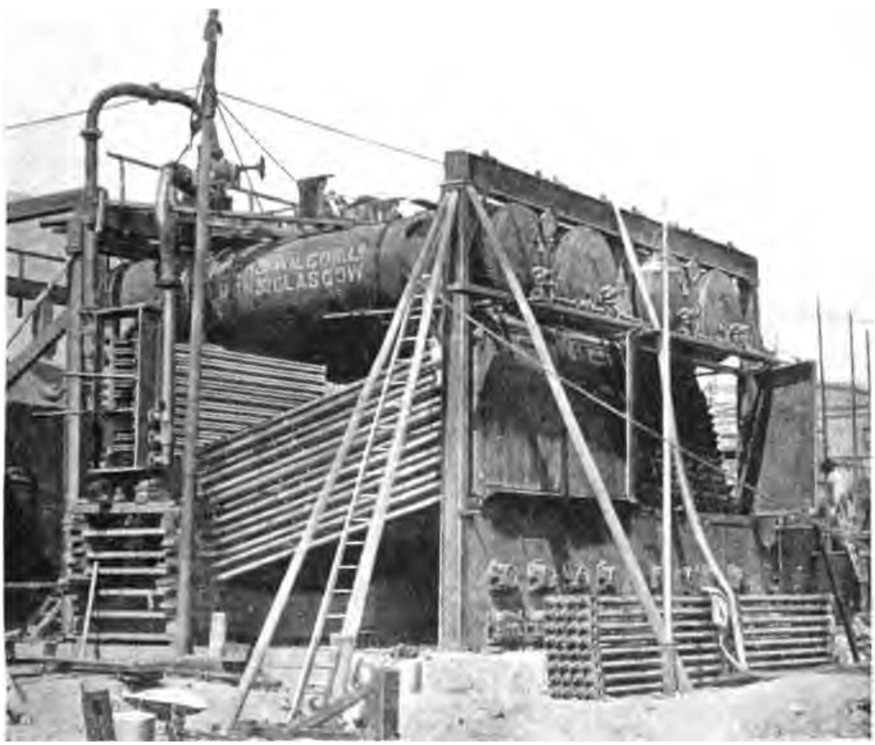


FIG. 24.—Two Babcock & Wilcox Boilers, each of 5,730 sq. ft. heating surface; erected in South Africa.

to size, and the tubes expanded into position. These rows, or units, are connected with the steam drum above and the mud drum below, by short tubes expanded into position; none of the joints in the tube connections depend for tightness on bolts or packing material.

Each vertical header is bored through both its sides, and the openings on the faces closed by machine joint plates. By removing these joint plates the whole interior surface of any tube can be scraped, cleaned, and inspected. The whole boiler is suspended from girders resting on columns,

and the brickwork setting is built after the boiler is in position, as is the case with the multitubular type. By an arrangement of baffle plates the products of combustion are made to pass three times through the rows of tubes before escaping to the chimney. As heated water tends to rise, the circulation through the inclined tubes is not only rapid, but all in one direction; there are no conflicting currents, and all parts of the boiler are kept at nearly equal temperature. Too much water space results in slow steaming, and too much steam space in losses through radiation. In this boiler the proportions have been arrived at after years of experiment, and the result is a boiler that can be driven to the utmost, and yet will carry a steady steam pressure and water level, and will always furnish dry steam. Perfect combustion is assisted by the numerous deflections the gases experience in their passage around the staggered tubes, tending to thoroughly mix the air with the carbon and hydrogen of the fuel.

In common with other externally fired boilers, the large furnace is well suited to wood fuel. Some of the results obtained under test and working conditions are referred to in the following chapter.

CHAPTER V.

CHIMNEYS—FUEL—FEED.

Chimneys, Height and Area of, Draught, Construction, Brick, Masonry, and Iron—Petroleum—Coal—Wood—Feed Water, Impurities, Heating—Methods of Feeding—Tests for Impurities.

Chimneys.

BEFORE putting up a chimney two important dimensions must be fixed, its area and height; two points of secondary importance being its position and method of construction. On the flue area depends the number of cubic feet of gas discharged in a given time; but this also depends on the speed at which the gas is travelling, which, in turn, depends chiefly on the height of the chimney and partly on the temperature of the gas. Thus it follows that area and height are closely connected, and, within limits, a deficiency of one may be corrected by an excess of the other. As from 250 to 300 cub. ft. of air are required for the combustion of each pound of coal, the area of the chimney flue bears a distinct relation to the fuel consumption. The rule is, fifteen times the fuel consumption in pounds per hour divided by the square root of the height of the chimney in feet, gives the flue area in square inches. But the rate of combustion varies, it may be 10 or 20 lbs. of coal per square foot of grate per hour; and even if it were possible to predetermine the exact consumption, altering conditions might upset calculations. In practice the common rule is to make the flue area equal to one-tenth of the grate area for wood and to one-eighth the grate area for coal.

Height.—Under given conditions the velocity of the draught depends directly on the height of the chimney, being due to the difference in weight between the column of heated gas within, and that of an equal column of air outside the chimney. This explains why the boiler steams better at night in tropical countries, and why a given height of chimney is less effective there than in a colder climate. A chimney works at its best and at its fullest capacity when the gas within is expanded by heat to twice the volume of the external air; this occurs when the gases are escaping at 491° Fahr., and the thermometer outside stands at freezing point.

Since the draught can always be checked and controlled by dampers, there is little danger of having too high a chimney; but want of height will diminish the fuel consumption and consequently the evaporative power of the boiler.

The intensity of the draught is measured by the height of the column of water it balances. A chimney, 70 ft. high, will give a draught pressure equal to half-an-inch of water, corresponding to a velocity of about 30 ft. a second; this is the minimum velocity of draught in use when good and rapid combustion are desired. Doubling the height of the chimney doubles the velocity and the pressure of the draught, a 140-ft. chimney yielding a draught equal to 1-in. water pressure, or a velocity of 66 ft. a second. Since the fuel consumption depends so largely on the height of the chimney, and the power on the fuel consumed, it is, in many cases, possible to obtain increased power by lengthening the chimney and burning more fuel in a given time.

As instances of extremes of practice, there were on the Colar Goldfield three Cornish boilers, each 6 ft. by 20 ft., connected to a chimney only 50 ft. high and having a flue area of 16 sq. ft.; the draught, as might be expected, was sluggish, and briquettes could not be burnt, as the cementing material melted and choked the firebars. On the other hand, in Colorado, two multitubular boilers, 4 ft. by 14 ft., were connected with a stack 520 ft. high—needless to say it had not been built. It happened in this way: the boilers were placed in a chamber at the end of an adit, and, as the upper part of the shaft was disused, it was sollared over and the uptakes connected with it. The area of the shaft was much greater than was necessary, and down-draughts doubtless interfered with the up-draught; still the boilers steamed well on the poorest fuel, and the fire lifted from the bars when the dampers were widely opened; all coal had to be thoroughly wetted before being used. As the external temperature was generally below freezing point, often below zero, the draught must have been equal to nearly 4 in. of water.

Position.—The site selected for the chimney should afford a sound foundation at a moderate depth below surface, and should be such that the flues lead to it without quick turns or right-angled bends. If the site stands above the level of the boilers, the height of the chimney is increased without extra cost, as the effective height is the difference in level between the firebars and the chimney cap. Finally, the position of the chimney must not interfere with additions or extensions to existing plant.

Construction.—Stone, bricks, and iron are the materials used; but bricks are seldom obtainable, and we are reduced to the choice of either stone or iron. When building materials can easily be procured, a stone erection will probably be cheaper for really permanent work, since the

expense is confined to the first cost; if well built, the chimney should require no repairs during the ordinary life of a mine. The weight of a stone stack is considerable, and the foundation must be carried down into firm pick ground; should there be any doubt as to the soundness of the bottom, the lowest courses of masonry should be footed out to distribute the weight. Externally the stack may be square, octagonal, or round, the latter section being less affected by wind pressure and permitting a reduction in the thickness of the walls. The square shape is simplest and should be adopted when the labour available is not of a high order. Nothing is gained by tapering the internal flue, but a round flue gives slightly better results than a square one. The external diameter at the base will be about one-tenth of the total height; in some countries it is necessary to exceed this width, as masonry work of less than 15 in. in thickness at the top cannot be relied on. When the flue is of sufficient area to afford working room, the chimney may be built from within and much scaffolding dispensed with; but this is not often the case. Correct batter is maintained by trial with plumb staffs, having the right amount of taper, generally one-third of an inch to the foot, planed off each side. When wood is to be the fuel, it is advisable to let the central flue of the chimney commence below the level at which the boiler flue enters; the well thus formed receives fine ashes and prevents them from blocking up the chimney base.

A masonry chimney 100 ft. high, with a flue 4½ ft. square, would have walls 3 ft. thick at the base, giving a total base diameter of 10½ ft.; by batter the thickness of the walls would be reduced to 15 in. at the top.

A round brick stack of the same height would be one brick thick for the top 25 ft., increasing half a brick for each 25 ft., and giving a base diameter of 9 ft. In high-class work, when all courses are to be kept level, it is essential that each mason changes place daily with the man opposite him, since no two lay joints of exactly the same thickness.

Before the scaffolding is removed, the lightning conductor should be securely fastened in position, with points spread well above the cap of the chimney; it should be made of copper, which is a better conductor than iron, and less liable to corrosion. The lower end should be fastened to an iron or copper plate, and either grounded in a damp place, or buried in a pit with charcoal around it.

Iron Chimneys.—These have the advantage in prime cost, their life is generally sufficient for mining requirements, and they can be taken down and re-erected at a moderate outlay; for these reasons they are more extensively used than any other kinds.

Portability is secured by making them in sections, to be bolted or riveted together at destination. These sections differ in diameter, that they may be nested for shipment, and diminish in thickness from the bottom to the top. Thus in an 80-ft. stack there will be four 20-ft. sections

of $\frac{5}{16}$, $\frac{1}{4}$, $\frac{3}{16}$, $\frac{1}{8}$ in. thick, respectively. The lowest section is secured to a cast-iron sole plate bolted to the masonry, but a wrought-iron angle ring may be substituted for the plate if portability is essential.

Wire guys are attached at about two-thirds of the total height; they must be well spread and anchored in all countries subject to monsoons and other violent winds, the stability of the chimney being increased by a sound connection to a substantial masonry base.

The method of erection depends on the height of the chimney and the gear available; if not exceeding 80 ft. in height they may be lifted by a single derrick pole or pair of sheer legs; those from 80 to 120 ft. in height may be raised by a system described in the chapter on "Tackle." When exceeding this height they are usually built up from below, the top being steadied and held vertically by wire guys as the lower part is jacked up and sections added at the ground level.

The accompanying views of the stages of erection of a 110-ft. chimney stack at the Abosso mine (Figs 25, 26, 27) will be of interest.

The following is an extract from a table kindly supplied by Messrs Babcock & Wilcox, Ltd., and gives the sizes of chimneys required for different rates of evaporation: —

Side of Flue in Inches.	Height in Feet.									
	50	60	70	80	90	100	110	125	150	175
16	700	800	900	...	...	...	...	...	...	...
24	2,000	2,200	2,400	2,500	...	...	...	...	...	...
30	...	3.500	3,800	4,000	4,300	...	...	...	...	...
35	...	...	5,500	5,900	6,300	6,600	...	...	...	...
43	...	...	...	9,400	9,900	10,500	11,000	11,700	...	...
48	...	...	...	10,900	12,900	13,500	14,200	15,100	16,600	...
54	...	...	...	15,200	16,100	17,000	17,800	19,000	20,800	22,500
64	...	...	...	...	23,800	25,100	26,300	28,100	30,700	33,200
	Evaporation in pounds per hour.									

Fuel.

Although not extensively used in mining work, crude petroleum is one of the most perfect fuels; on an average it contains 88 parts of carbon, 11 of hydrogen, and 1 of oxygen. The calorific value of this crude oil is about 20,000 B.T.U., and with proper precautions it can be fired in almost any furnace. It must first be atomised or broken up, in order that it may burn readily or almost instantaneously; this is effected by spraying by means of pumps, compressed air or steam, or by vaporising.

Of these systems, spraying by pumps may be considered the crudest,

FIG. 25.—Raising a 110-ft. Chimney Stack at the Abosso Gold Mine. (Position I.)

[To face p. 68

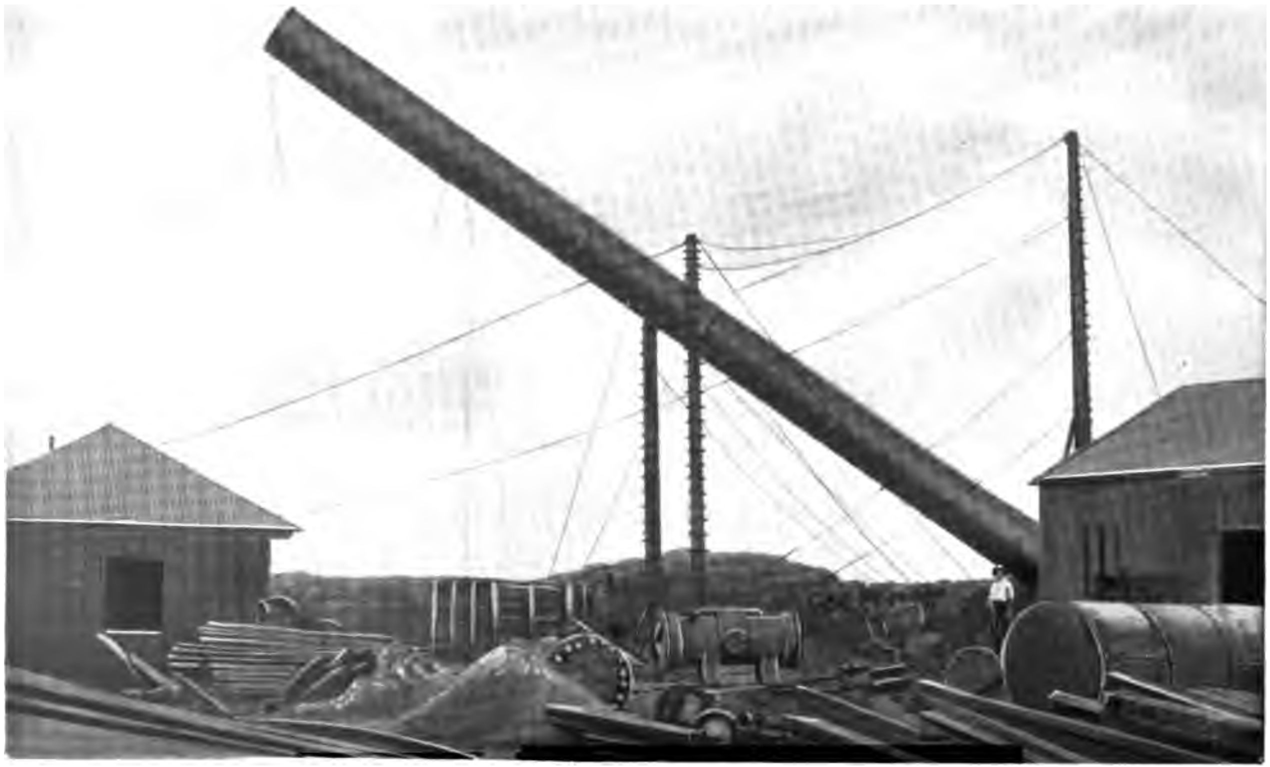


FIG. 26.—Raising a 110 ft. Chimney Stack at the Abosso Gold Mine. (Position II.)

[To face p. 68, after Fig. 25.

FIG. 27.—Raising a 110-ft. Chimney Stack at the Abosso Gold Mine. (Position III.)

[*To face p.* 68, *after* Fig. 26.

and is suitable only when the interior of the furnace is covered with a brick lining or a coke bed from which the heat is not rapidly abstracted, a temperature high enough to vaporise the incoming spray being retained; its efficiency is about 12½ lbs. of water evaporated per pound of fuel.

When the vaporising is effected by steam or compressed air, the particles of oil are finer, the atomising more complete, the brick lining may be partly dispensed with, and a brick arch or small coke bed substituted; the evaporative efficiency is higher, running up to 13½ lbs. of water at 212° Fahr. from each pound of fuel.

But the best results are obtained when the oil is completely vaporised or turned into gas. This is effected in a separate vessel, the oil, in its passage from the tank to the burner, usually passing through one or more coils of pipe exposed to the fire. The vaporising begins about 120° Fahr., the oil boils at 395° Fahr.; the more volatile constituents are then driven off, and solid carbon deposited; this is the reason why the nozzles of burners choke. One pound of vaporised oil will evaporate 16 lbs. of water at 212° Fahr.

As compared with coal, less than half the weight of fuel is required for the same work, admitting a considerable saving in transport. Being easily managed and regulated, one man is able to look after a whole battery of boilers; the steam pressure being easily controlled remains more constant, consequently the wear and tear on engines and boilers is reduced.

When spray burners give trouble it is generally on account of water in the oil, the flame then becomes intermittent, being extinguished while water is passing through the jet, and rekindled by the heat of the furnace when the oil spray takes the place of the water. The vaporising process is least liable to derangement in this respect.

Coal.—Coal is divided into two classes, anthracite (the hard, almost smokeless steam coal), and the bituminous, or ordinary household variety; there are, however, many subdivisions in each class. The calorific value of any coal lies almost entirely in the quantity of carbon it contains; a high-class British steam coal contains about 88 per cent. of carbon, and if consumed under theoretical conditions, produces 15,000 B.T.U. Outside the laboratory coal never is consumed under theoretical conditions; the quantity of air is too great or too little for perfect combustion; there is loss of heat up the chimney in the form of draught, and other losses by radiation and leakage of cold air through the boiler setting. In practice each pound of coal evaporates from 5 to 10 lbs. of water; in ordinary mining it would be safe to put the average at 7 lbs. The actual quantity of coal burnt per square foot of grate depends on its quality and on the draught; it may be averaged at 12 lbs. per hour; then 12 (lbs. of coal) multiplied by 7 (lbs. of water) equals 84 lbs. of feed water evaporated per hour on each square foot of grate, equal to very nearly 3 H.P.

In recent years few boilers have been more carefully tested than the water-tube. The Babcock & Wilcox boiler, for instance, has been shown capable of evaporating 10 to 12 lbs. of water at 212° Fahr. per pound of fuel, and of burning 30 to 40 lbs. of coal per square foot of grate per hour under a draught pressure of 1 in. of water. Some tests made by Professor Henry Robinson on a battery of boilers of this make are instructive in showing the difference between the theoretical and practical evaporative power of fuel, and how that difference is accounted for. In this case the coal contained 14,400 B.T.U., of which 10,463 B.T.U. were transferred to the water in the boiler, an amount which represents 72.65 per cent. of the total heat value of the fuel. Of the remainder, 12.45 per cent. were lost in flue gases, 12.7 per cent. in radiation and ashes, 2.2 per cent. by incomplete combustion.

Another test on the same make of boiler, but burning wood and supplying steam to triple-expansion engines, showed a consumption of 50.5 lbs. of wood per square foot of grate per hour, equal to 4.18 lbs. per I.H.P. per hour. At a large spinning mill in India an instructive test was made when coal and wood were used on alternate days, the consumption being 6,000 and 15,000 kilogrammes respectively, a proportion of 1 to 2½.

The various kinds of coal, English, Australian, Indian, and South African, differ considerably in the proportion of carbon and hydrogen they contain, and consequently in their calorific value. In dealing with either, the actual evaporative effect depends on the combustion and efficiency of the boiler; while the power ultimately resulting is decided by the efficiency of the motor. The following table shows to what degree the power obtainable, with different fuels and heating surfaces, depends on the motor efficiency: —

Engine.	Square Foot of Heating Surface per I.H.P. per Hour.		
	Oil.	Coal.	Wood.
High pressure (180), triple-expansion, condensing	3	3½	4
Ordinary pressure (160), triple-expansion, condensing	3¾	5	6
Triple-expansion, condensing	5	7	8
Compound, condensing (120 lbs.)	5	7	8
Compound, non-condensing	6¼	8	10
Ordinary high pressure, non-condensing	8	10	11½

The subject of firing is referred to in the following chapter, but it is worthy of note to what small extent mechanical stokers are used in mining. This may be due to prejudice, aptly described as "the outcome of unwritten experience," and the arch-enemy of all innovation; but the innovation, if sound, always triumphs in the end, as the ore-feeder and

rock-drill testify. Perhaps managers fear some complex machine, easily deranged, and not sufficiently elastic for varying requirements of power; possibly some of the earlier forms were open to these objections. The modern chain-grate stoker, however, needs only to be seen to be appreciated; the whole machine is mounted on rails, and as easily run out for inspection as an ore-feeder, and can be placed in the hands of any native fit to handle a donkey engine. This arrangement has proved thoroughly reliable; it reduces the labour of firing to a minimum, and it gives important aid to complete combustion by ensuring a regular and even, yet adjustable supply of fuel.

Wood is extensively used as fuel in the early stages of prospecting and development, frequently giving place to coal as the demand for power increases, the surrounding forest cleared, and the means of transport improved. Before being burnt, the wood should be at least half dry, which means in hot climates that it is cut and stacked into cords two or three months before it is required for use. The cord measures 4 ft. by 4 ft. by 8 ft., but the actual number of cubic feet depend on the stacking, and the number of hollows and arches artfully concealed in the pile. In any case the local varieties would necessarily be used, whatever their nature; but as a general fact it should be remembered that the different kinds of timber vary greatly in their calorific values.

Weight for weight, there is no great difference in the evaporative power of light and heavy woods, and since it is bought by measurement, the weight of any particular wood is a fairly safe indication of its value as fuel. A cord of heavy wood, such as oak, teak, mahogany, or West African kako, will have about twice the weight and twice the evaporative power of an equal measurement of fir or other light wood.

In order to use this fuel to advantage, the furnace should be roomy and the fire doors of ample dimensions; externally fired boilers are more suitable than other varieties. As large quantities of ashes are produced, the firebars should be more widely spaced than for coal, and be protected by an ash pit of extra depth.

When comparing wood with coal, few data are available, except laboratory tests, which give coal a value of twice the same quantity of oak, and about four times the same quantity of lighter wood. But we are more concerned with the humble efforts of the coloured gentleman whose sole object is to fill the furnace to the utmost, and secure a prolonged interval for meditation; under these circumstances 1 ton of coal is equal to 2½ or 3 cords of heavy wood, and about 5 cords of the lighter kinds.

To ascertain the relative cost of different fuels, a test was made on a horizontal, geared, pumping engine steamed by a Cornish boiler; the weights were carefully taken and the load kept constant, but as the load was light, the conditions were entirely in favour of wood.

	Fuel.		
	Wood.	English Coal (West Hartley).	Australian Coal (Newcastle).
Duration of trial	8¼ days.	5 days.	6½ days.
Size of wood pile consumed (in feet)	47 × 9 × 2¾	...	...
Weight of fuel consumed	15¾ tons.	4 tons 6 cwt.	5 tons 6 cwt.
Cost per ton (in shillings)	12	57	51
Cost per day (in shillings)	22	49	41

Under these conditions 1 ton of English coal proved equal to just over 2 tons of firewood.

Feed.

The water fed into the boiler should be clean and hot, conditions too seldom realised in practice; often the water pumped from the mine is accepted as the only feed available. Other alternatives are neglected, as entailing trouble and expense, nor is much serious effort made to improve the mine supply and render it more suitable for boiler use. Mine water is muddy, as the result of operations underground, that is, it contains mineral and organic matter in suspension and solution; filtration is an obvious remedy, but few mines are provided with the apparatus required.

Mineral matter, being heavier than water, will gradually be deposited if the water is not in motion; the feed is therefore made to pass through settling tanks in which the grosser impurities are deposited. As generally arranged, these tanks are deficient in two respects; they are of insufficient capacity, therefore the water does not become quiescent or remain in that state long enough to deposit the impurities; secondly, the arrangement seldom permits separate tanks being disconnected for cleaning.

The set should consist of three tanks, their size depending on the quantity of feed required; an allowance of 6 ft. square by 3 ft. deep for each 100 H.P. will be sufficient. Their tops are preferably fitted with loose lids, and the quantity of water admitted should be, as nearly as possible, that of the feed required, any overflow increasing the deposit. The water should enter and leave the tanks near the top, entering No. 1, overflow to No. 2, and thence to No. 3; to the latter the feed suction pipes are connected, with a branch to No. 2 tank for use when No. 3 is being cleaned.

These suction pipes should be connected at least a foot from the bottom of the tanks, and the incoming water arranged to miss any tank in the series for cleaning purposes. Such an arrangement, if attended to at intervals, will collect large quantities of mud and be found to effect considerable saving in boiler cleaning, besides permitting a higher evaporative duty.

It must not be concluded that, because the mud is deposited and the water looks clear in a glass, it is fit for boiler use ; deleterious matters may still be present, though invisible, being in a state of absolute solution. When the water is heated it no longer has the power of holding these substances in solution, and they become palpable deposits in the boiler.

Chief among these substances are—Carbonate of lime, soluble 1 part in 62,500 of water, and becoming insoluble at a temperature of 302° Fahr., when it forms a soft muddy deposit.

Sulphate of lime is soluble 1 part in 500 of water, and becomes insoluble at 302° Fahr., forming a hard scale.

Carbonate of magnesia is soluble 1 part in 5,500 of water, while silica and oxide of iron become insoluble at boiling point.

Should there be traces of carbonic acid in the water, the quantity of carbonates held in solution may be greatly increased ; these minerals are as actually dissolved in the water as sugar may be, and cannot be extracted by any process of settling or filtration. Here precipitation comes to our aid, and is brought about by freezing, boiling, or adding chemicals to the water.

Lime compounds cannot be precipitated by boiling, since they do not become insoluble at a lower temperature than 302° Fahr., corresponding to a steam pressure of 70 lbs. ; but carbonate of lime may be deposited in the settling tanks by the addition of small quantities of caustic lime. The various nostrums and compounds which may be added to the feed vary from bark to petroleum, but at the most they only ensure a soft deposit instead of a hard scale ; the better plan is to heat the feed at least to boiling point before use.

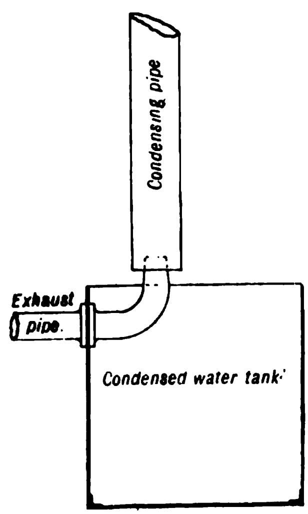


FIG. 28.—Arrangement for Condensing Exhaust Steam.

Owing to decomposition of pyrites, free sulphuric acid is often present in mine water. The author once had a battery of nine multitubular boilers in which sets of tubes never lasted more than eight months, being eaten nearly through by acid in that time ; the trouble disappeared on neutralising the feed water with ammonia.

If nothing but bad feed water is available, it is worth while going to considerable trouble to improve its quality, but a purer supply may often be found in a neighbouring spring or stream. An alternative plan is to condense the exhaust by passing it through a coil surrounded with cold water. In countries where water is scarce, the arrangement shown in Fig. 28 may

be used ; its efficiency increases with the height of the vertical pipe, a disused smoke-stack being often used if available for this purpose.

When condensed steam is returned to the boilers, engine lubrication must be reduced to a minimum, or the feed passed through oil extractors, as oil and grease combine with magnesia salts, forming a tough scale very difficult to remove from boiler surfaces.

In lieu of extractors, much of the oil may be removed by allowing the condensing tanks to overflow at intervals, but hot feed is wasted in this way. The necessity for using every means of purifying the feed is apparent when it is realised that a scale only a sixteenth of an inch thick diminishes the conductivity of the boiler shell by 20 per cent., while a quarter-inch scale is responsible for a diminution of 60 per cent.

Before it is pumped into the boiler the feed must be heated, and every unit of waste heat that can be utilised in this way is a step towards boiler efficiency. Advantage will therefore be taken of any water used for cooling purposes in tuyeres and water jackets, the supply receiving additional units from heaters through which exhaust steam or waste flue gases pass.

Of heaters warmed by exhaust steam, those with straight tubes are more easily cleaned and examined ; they should be fitted in duplicate for alternate use.

No exhaust heater will actually boil the feed water, about 200° Fahr. is the most that can be expected ; to exceed this limit, some form of economiser is required. Economisers are usually nests of tubes placed between the boiler and the chimney, and provided with some mechanical appliance for cleaning their external surfaces.

When the feed has been previously heated by exhaust steam, they are capable of raising its temperature to 250° without seriously interfering with the draught. A gain of about 12 per cent. in fuel results from their use, but, perhaps owing to the additional mechanical complication, they are not generally adopted. The hotter the flue gases the greater the advantage of economisers, or in other words, the more wasteful the boiler, the greater the opportunity for the economiser.

The feed should be as regular and as constant as possible, as much water being pumped into the boiler per minute as the engine requires in steam ; the most economical form of pump being one driven directly from the main motor by belt or gearing. Injectors rank second, and direct-acting steam pumps last, the latter costing about 13 per cent. more in fuel than when the feed pump is actuated by the main motor.

Simple Tests for Feed Water.

If Acid or Alkaline.—Test with litmus paper. If blue paper does not turn red, the water is not acid ; if red paper does not turn blue, the water is not alkaline.

Carbonic Acid.—Place a sample of the water in a test tube and add lime water. If carbonic acid is present the sample becomes milky, and again clears on adding hydrochloric acid in small quantities.

Sulphate of Lime.—To a sample of the water in a test tube add chloride of barium. If sulphate of lime (gypsum) is present a white precipitate is formed which does not dissolve in nitric acid.

Magnesia.—Boil a sample of the water in a test tube, and add a small quantity of carbonate of ammonia and phosphate of soda. Magnesia forms a white precipitate.

Iron.—A drop of ferrocyanide of potassium will colour the water blue if iron is present.

Copper.—Soak filings of soft iron in the sample, add chloride of ammonium. The water turns blue if copper is present.

Lead.—Add a few drops of cochineal to a sample in a test tube. Lead is present if the water turns blue.

CHAPTER VI.

MANAGEMENT OF MOTIVE POWER.

Protection of Machinery not in Use—Overhauling Boilers, Engines—Boilers under Steam—Firing—Engine under Steam—Taking Diagrams—Detecting Errors—Calculating Horse-power—Periodic Tests.

Preservation of Machinery.—Machinery when not in use is liable to rapid deterioration unless proper precautions are taken for its preservation. Working surfaces that should be smooth and polished as glass may be ruined by a few weeks' rusting in wet packing. The extent of the precautions to be taken depends in a great measure on the time the machinery is to be idle. For engines in occasional use, say once or twice a week, nothing more is necessary than a good oiling when shutting down, and a turn round by hand every day. Boilers idle for a fortnight at a time may be closed up and entirely filled with water.

When the period is likely to exceed a month, all engine packing should be withdrawn, and both interior and exterior working surfaces, and all polished parts, covered with cylinder oil or melted tallow. The boiler, if quite tight, may be filled with water, but the smallest leak or weeping will lead to corrosion. It is on the whole safer to drain the boiler and paint the interior with linseed oil or whitewash, leaving the doors off so that air may circulate freely. A boiler in this condition, and protected by a sound roof, may be left indefinitely. The iron chimney will be sufficiently protected by a metal plate laid across the top to keep the rain out.

Timber is more difficult to preserve, for when white ants are prevalent they soon appear on the scene if the machinery is idle and vibration stopped. They will not touch woodwork painted with cyanide solution, but the effect of the cyanide is soon lost in places where it is exposed to rain.

Examination of Boilers.—On taking charge of a mine that has been idle, when the state and condition of the plant is not known, it is best to take nothing for granted, and to submit each part to a searching examination such as all steam plant should undergo at least once a year.

The flues are opened and cleaned, portions of the setting on which the boiler rests being removed and the shell examined for corrosion. The masonry work of the flues should be carefully inspected and repaired if

necessary, any leakage of cold air being detrimental to the performance of the boiler. Examine for traces of corrosion around mud holes and blow-off cocks. The lower parts of the fronts are liable to damage through accumulations of damp ashes.

Internally, after a thorough cleaning and scaling, the thickness of the flues can be tested by a small hole bored through the crown of the furnace; it can be afterwards screwed and plugged. The surface of the plates should be searched for pitting, and the seams for grooving. These grooves, sometimes quite deep and seriously weakening the plate, are especially liable to occur wherever free expansion has been checked by stays or extra thickness of metal. Bulges and blisters, if small and local, may be patched by a plate bolted over them. Riveting is seldom successful unless done by men accustomed to such work. Cracks may be stopped by a hole drilled through the sheet at each end and a plate bolted over the whole. Such repairs naturally decrease the strength of the boiler, and the working pressure must be reduced accordingly. Renew safety plugs, and repair the furnace bridges. Remove warped and distorted firebars, they waste more fuel than new ones cost.

When adding new firebars see that there is room for free expansion at their ends. The various mountings should now be overhauled, the safety valves ground in, taking care that the bearing surface of the valve on its seat does not exceed a sixteenth of an inch in width. The safety valve lever should work in an open fork; when in a closed loop, native firemen have been known to wedge it down to prevent it from *leaking!* All valves will require packing and grinding, especially stop, check, and blow-off valves. The feed pumps will be thoroughly overhauled to ensure that their pistons, plungers, and valves are in good order.

See that the pressure gauges are not stuck, and that their hands point to zero. Water gauges require grinding and packing. Those packed with asbestos can be renewed with shredded asbestos mixed to a dough with graphite and naphtha (kerosine may be used but is not so good). Insert the packing in thin layers around the plug, and ram each layer solid before putting in the next.

Finally, having gone carefully over every fitting and mounting, raise steam and test pipe joints and connections for leakage. There may be neither time nor opportunity to attend to such things when once work is in full swing.

The steam gauges may now be checked by the indicator, and the safety valves tested to see that they lift at the correct pressure, as shown by the gauge.

Externally fired multitubular boilers, unless corroded elsewhere by some particular leak, are generally thinnest in the shell plate over the fire, about 4 ft. from the dead plate. In retubing them, the old tubes are cut in two or three places with a cross-cut chisel, longitudinally, through that part

expanded into the tube plate; but to avoid injury to the plate, the cut should not extend quite through the tube. The ends are then knocked inwards and doubled into the bore of the tube; when loosened at both ends the tubes fall to the bottom of the boiler and are withdrawn through the mud hole door.

The new tubes may be fit to insert as they are received, or may require annealing to prevent their ends splitting when they are being expanded; they are passed through the front plate and should not be expanded more than is necessary to make them steam tight. This is generally the case when the path made by the rollers of the expander can be just felt with the finger; a hydraulic test should then be made before any further expanding is done. A careless workman may expand the tube to such an extent that the metal is weakened, and leakage soon follows. In fitting the stay tubes, the inside nuts are first tightened to a firm bearing and the outer ones screwed tightly against the sheet, the joints being made by grommets of copper wire or gauze and red lead. In an emergency a leaky tube may be plugged by a long bolt, passed from end to end, with a washer and joint material at front and rear.

Water-tube boilers are cleaned by removing the caps at the ends of the tubes; the interior of each tube can then be scraped and sluiced out with water, the scale being more easily removed when wet. In most boilers of this kind the baffle plates require attention, they are liable to warp with the heat and are easily displaced by careless firemen; in either case heat escapes to the chimney instead of being compelled to circulate around the tubes.

The Engines.—In order to thoroughly examine the state and working condition of the engines, all covers will be removed and the cylinders, air-pump barrels, and other bored surfaces gauged for wear. The piston rings will be set or renewed, self-expanding rings may be opened by gentle hammering on the inside with a round nose hammer. Brass rings may be cast to tide over an emergency; the final turning to gauge should be done after they are cut, the ends being sprung together and held by clamps in the lathe.

The slide valve and face will probably want trueing, but no good will be done by working the two faces together; the valve should first be trued on a plane surface and the cylinder face filed and scraped to fit it. In Corliss gear there is play in the joints to be taken up, trip plates to be reversed or renewed.

Reversing gear generally wants tightening up, joint holes reamed a size larger, and new pins fitted; new sliding blocks should be fitted in slot links. Glands that are worn should be bored out and brushed with brass; a white-metal lining soon wears away, and is not worth the trouble it causes. The crank shaft will be lined and levelled up, the main and connecting rod bearings adjusted; test the cylinder clearance before replacing the covers,

and the valve setting before putting back the valve chest door. Any feed pumps connected to the engine are sure to require overhauling, and feed heaters scaling and cleaning. The interior of jet condensers and injection pipes soon gets covered with scale when dirty water is used; they require cleaning at frequent intervals. Under similar circumstances, surface condensers suffer from dirty and leaky tubes; they are easily tightened when each tube is secured in the plate by a ring of packing and screwed gland, and may be cleaned by drawing them between two files, placed vee shape, in a vice. The smaller details, drain cocks and lubricators, will also require attention. In addition to the foregoing, each engine, according to its work, will have special gear attached to it which must not be neglected. In a mill engine there will be the transmission gear, shafting, and belts; in a pumping engine the rods and bob, and in a winding engine the ropes, sheaves, brake gear, and drums.

Steam may now be raised for a trial run, diagrams taken from the engine, and connections tested for leakage.

Boilers under Steam.—When at work the water level is the most important thing; it should always be kept, as nearly as possible, at the same height by constant feed. The strains set up in the boiler by frequent changes of temperature are thus avoided, for few things are more injurious in this respect than large quantities of feed and fuel at irregular intervals.

The water gauges should be blown through frequently, and the try cocks tested at the same time, or they will be found stuck just when required for use. In internally fired boilers, the fusible plug is an excellent safeguard, but must not be relied on; like other automatic appliances, it is dangerous in proportion to the reliance placed in it, and a fusible plug may not be fusible if covered with scale.

In case of low water and danger of overheating, do not draw the fire, but cover it with ashes, earth, sand, or even fine coal; water must not be used, nor should the safety valve be opened, the reduced pressure enabling more water to turn into steam and thus lessening the already diminished supply.

Firing.—If coal is used, the fire may be from 6 to 10 in. thick, according to the draught pressure; but in any case it must be of even thickness and free from holes. Fresh fuel should be introduced often and in small quantities, the furnace door being kept open as little as possible. Constant stirring and poking should not be necessary, but if so, the draught is insufficient; some poor coals seem to have most effect when active combustion has ceased and the fire is a bed of glowing coke. Firebars should be freed from slag every shift, and warped ones removed when opportunity occurs; by admitting more air in places they cause the fire to burn unevenly; bars often get unduly heated, and sag through accumulation of hot ashes in the ash pit.

The same principles hold good when wood is used; but greater care must be taken to fire in small quantities, as this fuel contains from 20 to 25 per cent. of moisture, and the heat of the furnace is checked until this moisture is evaporated. The furnace must be of ample dimensions, the fire doors large, and the clear height above the fire at least twice as great as when coal is used. The bars should be covered with a bed of glowing charcoal; when wood is thoroughly consumed the residue is a fine white ash, not lumps of charcoal.

The safety valve levers are eased daily, to ensure the valves being free; the weights should be fastened in position and no other weights added. Pressure gauges are, or should be, connected to the boiler by a syphon, so that only water enters the gauge; they should be checked every few months by attaching an indicator in their place and observing if the pencil marks the same pressure as the gauge registers. In all classes of tubular and water-tube boilers the tubes should be cleaned every shift; this is easily done by blowing through, or around, them with a jet of dry steam; wet steam is useless for the purpose.

Do not blow the boiler off unless absolutely necessary, and then only a little at a time; the mud deposited around the blow off pipe is discharged in one or two seconds, and if this is done at regular intervals the boiler will never reach the stage when a total change of its contents is required.

A boiler disconnected for cleaning will be severely strained if blown down while the setting is still hot; one thing only is worse, viz., pumping in cold water to hasten the cooling. When one in a battery of boilers is being cleaned, it should either be isolated by self-acting valves, or the stop valve and blow-off be under lock and key; blowing off at intervals becomes a matter of routine with the attendant, and lives have been sacrificed through forgetting the men at work in the adjoining boiler.

The appearance of the boiler-house and engine-room is an indication of the state of the plant, and where dirt and leakage are absent, floors clean, fittings polished, and tools neatly kept, there is visible proof of care and attention on the part of the staff. These things tend to efficiency and are worth encouragement; while economic efficiency may be assisted by a record of the fuel and stores consumed, with a monthly bonus on the result.

Starting.—The engine is warmed before starting by opening both regulator and drain cocks slightly. When the valve gear can be disconnected and worked by hand, a little steam may be admitted to alternate sides of the piston. The engine should not be violently rocked, and reversed as it is turning centre. Move it as little as possible, bringing the crank into a favourable position and connecting the eccentric rod before starting. The lubricators will now require attention, the threads being adjusted to the oil feed required. Sight feeds are best for internal parts, but lubrication should be sparing when the condensed water is used for feed.

All lubrication should be minimum in quantity and constant in application, while the lubricant should suit the speed of the shaft and pressure on the bearing. A thin oil suits a fast motion and light load, more body being required for parts moving slowly under considerable pressure, such as crusher rolls and pumping cranks. In new or newly adjusted machinery, it is best to leave the bearings slack at first, and to tighten them gradually as they bed themselves after a few days' work. Hot bearings may be due to defective lubrication, tight adjustment, rough surface, or excessive load pressure, an indiscriminate application of water only makes matters worse. Apply antifriction grease and powdered graphite through the oil hole, and pour water only on the *shaft* or *neck of the bearing*. Frequent heating is probably caused by rough or scored surfaces, and the shaft should be drawfiled from end to end of the bearing with a dead smooth file, but do not polish with emery cloth; wash well with kerosine before assembling, and the brasses will soon work to an even surface unless deeply scored.

Running.—Clear, regular puffs of exhaust show valves and pistons correctly set and in good order; but when low pressure steam is used, or the cut-off is early in the stroke, the exhaust may no longer be sharp, though it should still be regular and even. On the other hand, the condensing engine exhibits no external sign, and the indicator is the only means of finding out what is going on within.

The indicator is an instrument needing no detailed description; it is made in many forms, but in principle they all agree with the original designed by Watt.

A revolving barrel covered with paper derives its motion from the engine piston, or some part connected to it, and thus represents on a reduced scale the motion of the piston.

A pencil controlled by the steam within the cylinder represents by its vertical movement the varying pressure on the piston. These two motions at right angles to each other produce a compound figure which would be a parallelogram, provided the steam pressure was constant throughout the stroke, the admission and release instantaneous, and there was no cushioning; conditions fulfilled by many forms of direct-acting pump.

In practice, a curved figure results which, when plotted to scale, gives the mean steam pressure on the piston. It also indicates the points of admission, cut-off, and exhaust.

The indicator should be connected close to the ends of the cylinder, holes for the purpose will generally be found near the covers. Diagrams may be taken by attaching the indicator to alternate ends of the cylinder, but this is open to the objection that the boiler pressure, or load, may vary in the interval, or the same stroke may not be given to the indicator

drum, making it difficult to compare results from opposite ends of the cylinder.

It is on all accounts preferable to screw a valve into each cylinder opening, and connect these valves to a common Tee, into which the indicator is screwed. Diagrams can then be taken from both ends of the cylinder without altering the setting of the instrument. Let the pipe connections be as short and direct as possible, blow them through with steam before attaching the indicator, and see that the instrument is clean and oiled. Motion is usually obtained from the cross-head of the engine, the return stroke being made by a coiled spring within the barrel.

Some care is required in arranging for this motion or a distorted diagram will result. The pull of the cord should be parallel with the bore of the engine cylinder, and the lever about twice as long as the

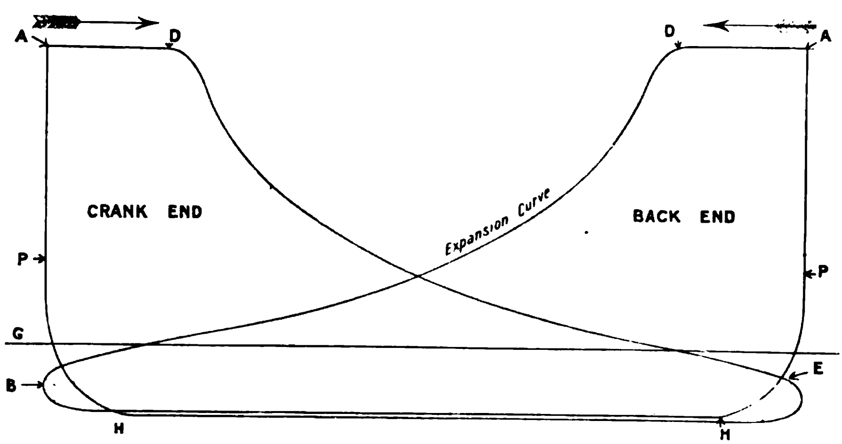


FIG. 29.—Diagram from Condensing Engine, steam cut oft at one-sixth of the stroke.

engine stroke. When the engine stroke is 5 ft., the lever will be from 8 to 10 ft. long, and the point in its length where the indicator cord is attached to obtain a 4 or 5 inch stroke will be several feet above the level of the instrument. Under these conditions the cord will not be parallel with the cylinder unless reducing wheels are used; an alternative plan is offered by compound levers, one pivoted above, and the other below, the centre of motion.

The length of the cord is now adjusted until the barrel makes nearly a full revolution with each stroke of the engine; but it must on no account touch the stops at either end of its stroke.

The two ends of a sheet of paper are now inserted between the clips on the drum, and the sheet worked down until it lies closely and evenly. Open the valve at one end of the cylinder and allow the indicator to work a few strokes to warm up; press the pencil against the revolving paper

no harder than is necessary to make a distinct mark. Now close the steam valve and connect the opposite end of the cylinder, taking a diagram in the same way; shut off the steam, while the pencil traces the horizontal atmospheric line.

Remove the paper and number the diagram, marking the front and back ends of the card; note also the date, time, load on the engine, number of revolutions, rate of expansion, and the readings of the steam, vacuum, and receiver gauges.

Fig. 29 shows a typical pair of diagrams taken from a condensing engine, steam being cut off at one-sixth of the stroke. The arrows show the direction in which the piston of the engine is moving. In these

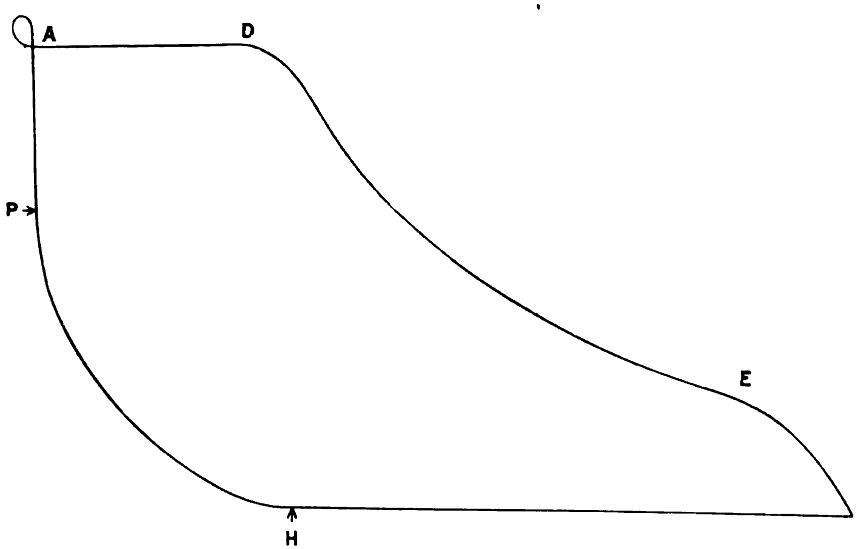


FIG. 30.—Diagram showing effect produced by too great an advance of the Eccentric. All points early.

figures all motion in a horizontal direction denotes movement of the engine, and all vertical variations represent fluctuations in steam pressure. At A the piston is on dead centre at the crank end, and moves in the direction of the arrow under full and steady steam pressure. At D the steam is cut off, and the pressure falls all along the expansion curve until at E the exhaust begins to open. The exhaust opens more widely and the pressure falls until the end of the stroke is reached. The horizontal line at the bottom of the diagram indicates the pressure in the condenser during the return stroke. At H the exhaust closes, cushioning commences, and the pressure rises until at P steam is admitted for the next stroke. G K is the atmospheric line, measurements above it are steam pressures,

below it, vacuum pressures; while the total measurement from top to bottom of the diagram gives the absolute pressure.

In Fig. 29 the points of steam admission, cut-off, and exhaust occur in their normal positions, and show that the valves and eccentric are correctly placed. Fig. 30 is a diagram purposely distorted to show what occurs when the eccentric is too far in advance of the crank. Here every point occurs too soon; the cushioning at H commences early, the full steam pressure A is on before the back stroke is completed, the cut-off is earlier than it is intended to be, and the exhaust is finished before the stroke is ended. The loop at A is caused by the piston moving against the steam and compressing it; partly, too, by the momentum of the indicator.

Fig. 31 shows the opposite defect; here the main points are all late.

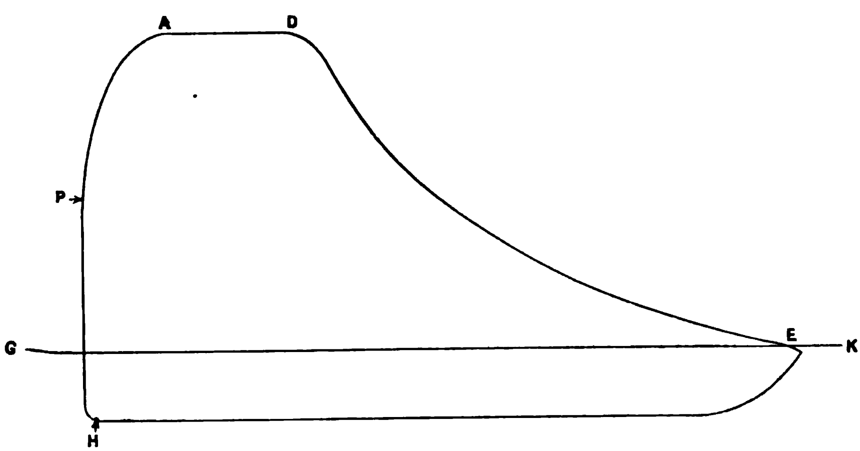


FIG. 31.—Eccentric not sufficiently advanced. All points late.

The exhaust is not closed until nearly the end of the stroke, showing scarcely any compression at H; the rounded curve from P to A indicates insufficient lead; and at E the stroke is finished before the exhaust opens. Evidently the eccentric is wrongly placed, and should be moved farther in advance of the crank.

When diagrams from both ends of the cylinder show the same defects as regards time, that is, when all the points are either early or late, the fault lies in the position of the eccentric. Should opposite defects appear, too early at one end and too late at the other, the length of the eccentric rods or valve rods requires adjustment. Like defects, eccentrics; unlike defects, rods.

In Fig. 32 the dotted line D E shows the effect of a leaky slide valve which admits steam after it is cut off and maintains the pressure above

the line of expansion curve. The dotted line A E may be caused by pipes and passages of insufficient area, which fail to deliver steam at the rate it is required; the same result appears when the regulator or throttle valve is partly closed. The dotted line P Q may be due to insufficient lead, but as other points in the diagram are correctly placed, it indicates a leaky piston. The whole figure is above the atmospheric line, as is the case in all diagrams taken from non-condensing engines.

When compound engines are being indicated, diagrams from the different cylinders should be taken as nearly as possible at the same time. The indicator may also be used for testing pumps and air compressors, and is a valuable check if screwed on in place of a pressure gauge; in that case the scaled length of the vertical line described by the pencil should correspond with the reading of the gauge.

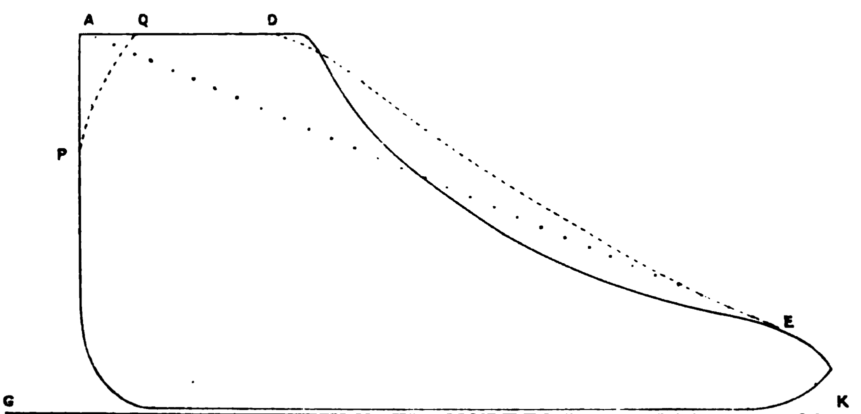


FIG. 32.—Indicator Lines showing Various Engine Defects.

Horse-Power.—To ascertain the horse-power, divide the length of the diagram into ten equal parts, and with the scale corresponding to the spring used, measure the whole width of the diagram, from top to bottom, in the centre of each division. Add these ten measurements together, strike off one figure on the right, and the result is the mean or average steam pressure throughout the stroke. Should the totals from opposite ends of the cylinder not agree, add them together and divide their sum by two.

This average pressure, multiplied by the area of the piston, and by the number of feet travelled by the piston per minute (stroke in feet multiplied by twice the number of revolutions), and divided by 33,000 will give the indicated horse-power.

In dealing with engines having more than one cylinder, the horse-power of each cylinder is found separately and the totals added together.

The indicated horse-power always exceeds brake horse-power, as the former includes all the power absorbed by friction in the engine, while brake horse-power is the actual power available at the crank shaft.

In this way a set of diagrams, taken every two or three months, not only shows the power developed, but illustrates the condition of those internal parts of the engine inaccessible to ordinary observation. Every six months or so it is advisable to have a more searching test, in which the boilers are included, to determine the cost of the power supplied.

As work may be hindered if fires are drawn at the commencement of the test, the results will be sufficiently accurate if care is taken that the state of the fires, the steam pressure, and the water level, are alike at each end of the test.

All fuel must be weighed, and credit given for any unconsumed; the amount of feed water is easily checked if a tank of known capacity is filled, and tallied each time it is emptied into the main tank. The safety valves should not blow, nor should the boiler be blown off if it can be avoided. The test should last as many hours as continuous observation can be arranged for; diagrams will be taken at regular intervals, not less than three times during the test. If no counter is available, the revolutions must be taken at different times and averaged; notes will be made of the pressures shown by the barometer, steam, vacuum, and receiver gauges; also of the temperature of the boiler-house, engine-room, feed, injection and circulating water, and the overflow from the condensers. From these data the boiler and engine efficiency are obtained separately—the boiler, in pounds of water evaporated per pound of fuel; and the engine, in pounds of steam or fuel per I.H.P. per hour.

CHAPTER VII.

PUMPING MACHINERY.

Pumping Engines, Types of—Geared—Direct-acting—Erecting—Connections—Pit Work—Plunger Lift, Fixing—Sinking Lift—Station Pumps—Riedler Pumps—Pumping by Water and Air Pressure—Direct-acting Pumps—Selecting a Pump for Required Duty—Fixing and Adjusting Direct-acting Pumps—Tailings—Centrifugal and Donkey Pumps—Overhauling.

THE pumping machinery used in mining may be divided into two classes: in the first, the motive power is at surface and the pumps actuated by rods; in the second, the pump and motor are combined, placed underground, and driven by steam, compressed air, or electricity; the latter class includes all station and direct-acting pumps.

Those driven by motive power from the surface have distinct advantages over underground engines. They are more economical, saving the inevitable percentage lost when power is transmitted by steam or compressed air; they are not affected by sudden inrush of water, and can be worked submerged if necessary; and the surface engine is generally in better order, as it affords greater facility for inspection and repair. In comparing the working cost of the two systems, it may be stated broadly that an underground steam engine will consume about three times as much steam as a condensing engine at surface doing the same work. The underground type, however, has an advantage in respect of prime cost and initial outlay, and on this account is often used for preliminary work and temporary purposes.

Surface pumping engines may be divided into two kinds; in one the piston rod is directly connected to the pump rods, in the other gearing intervenes between them. Mention of the first would be incomplete without passing reference to the Cornish pumping engine, with its honourable record of duty, regularly and economically performed; for many years this engine stood in the front rank as an economical producer of power, but has now given place to the multicylinder type.

Few examples of this class are to be found on foreign mines, as the cost of erection and transporting their massive parts has led to the adoption of smaller motors driven at a higher piston speed.

To this type belonged the well-known engines with 144-in. cylinders which drained the Haarlem Meer, a task which at the present time would be per-

formed by a comparatively small motor directly coupled to a centrifugal pump.

The Geared Pumping Engine.—In all except deep or very wet mines, this form of engine is in general use; it is usually arranged horizontally, and connected to the pumping crank by spur gearing. Such engines may be found on most goldfields, and are well suited to pumping from moderate depths; the gearing, usually five or six to one, permits a high piston speed in proportion to the pump travel, and thus reduces the motor to moderate weight. A variable pumping stroke is provided for by holes of different radii in the pumping crank.

Against them may be urged that on heavy loads the chattering and back-lash of the gearing has a disintegrating effect on the masonry, and for this reason the foundations have had to be rebuilt in several instances. There is also difficulty in handling these engines and starting under heavy loads; though this certainly might be avoided by using a pair of engines, by barring gear on the flywheel, or by detaching valve gear as used on many American patterns. The fact remains that these facilities are seldom afforded and, when the load approaches 400 ft. of 12-in. pitwork, starting a single engine on centre is neither easy nor devoid of risk to those turning the flywheel.

In erecting a horizontal geared engine of this kind, a line squared with the mine shaft and set off from the centre of the pump rods will be the datum from which the bob loading and pumping crank foundation are laid off. A parallel line to the right or left, and at the required distance from it, will be the centre of the engine. The distance from the pumping crank shaft to the main pump rods in the mine shaft will be the length of the sweep rod, added to the length of the bob from king post to pumping pin, minus half the versed sine of the arc described by the nose of the bob.

Should it be desirable to place the engine farther from the mine shaft, it can be arranged by introducing travelling rods between the sweep rod and bob. From these lines and measurements the work is laid off, as already described, the foundation for the pumping crank being a solid block of concrete if possible. Failing this, cement masonry may be used; if neither is available, the only alternative is to place the engine near the bob and tie the bob and engine foundations together with timber struts, so disposed as to take the push and pull of the sweep rod.

Care is required in running these engines, as the load is constantly varying in each half revolution of the pumping crank, being least when that crank is passing its dead centres. As sufficient steam must be admitted for the heaviest load during each pumping stroke, the quantity is more than necessary when little work is being done. For this reason the engine cannot be run at less than twenty or twenty-five revolutions a minute, and this may be faster than even the shortest pumping stroke requires to

cope with the water. Short of stopping the engine at intervals, the alternative is to pipe water back to the cisterns below in order to keep the pumps supplied; this method, involving waste of power, is effected by opening a cock near the foot of the column.

These engines are generally condensing, and part of the water raised to surface is used for injection or circulating purposes; as a safeguard a bye-pass should be provided, cutting out the condenser and enabling the pumps to be run non-condensing in an emergency. In preliminary work, pumping and hoisting are often performed by the same engine, a combination referred to in the following chapter.

Direct-Pumping Engines.—This class is represented by the well-known differential engine made by Hathorn, Davey, & Co. It may be asked why a direct engine of this type should be more suitable as regards weight and transport than the Cornish pattern; the reason is that several cylinders take the place of one large one, these are double acting instead of single, and the arrangement of valve gear permits a higher working pressure.

This engine is made single, compound, and triple expansion, and has a corresponding number of cylinders, placed tandem, and mounted on a bed-plate. A connecting rod attaches the end of the high-pressure piston rod directly to the bob and pump rods, the steam distribution in the cylinders being controlled by the ingenious differential valve gear from which the engine takes its name. (See Fig. 33.)

The valve motion is obtained from a freely suspended rocking link, worked at one end by the main engine, and at the other by a small subsidiary engine controlled by cataract gear; the valve spindle of the main engine is attached between these two extreme points. The motion of the rocking link due to the main engine tends to close the main steam valves, while that imparted by the subsidiary engine tends to open them. Thus the valves are closed by the main engine, while their opening and the extent of their opening is controlled by the auxiliary.

As this auxiliary is controlled by a cataract, it can be set to move at any rate which will admit the required amount of steam to the main engine. Should the speed of the main engine increase, either from increase of steam pressure or decrease of load, the main engine gains on the auxiliary, the closing of the valves is accelerated, and steam either throttled or cut off.

The gear therefore forms a sensitive governor acting directly on the steam valves. By the side of the auxiliary is another small cylinder in connection with a cataract, by which the interval between the strokes of the main engine can be regulated from a mere pause to fifteen or more seconds. As the result of this arrangement, pumping is economically performed even when the pumps themselves exceed the capacity re-

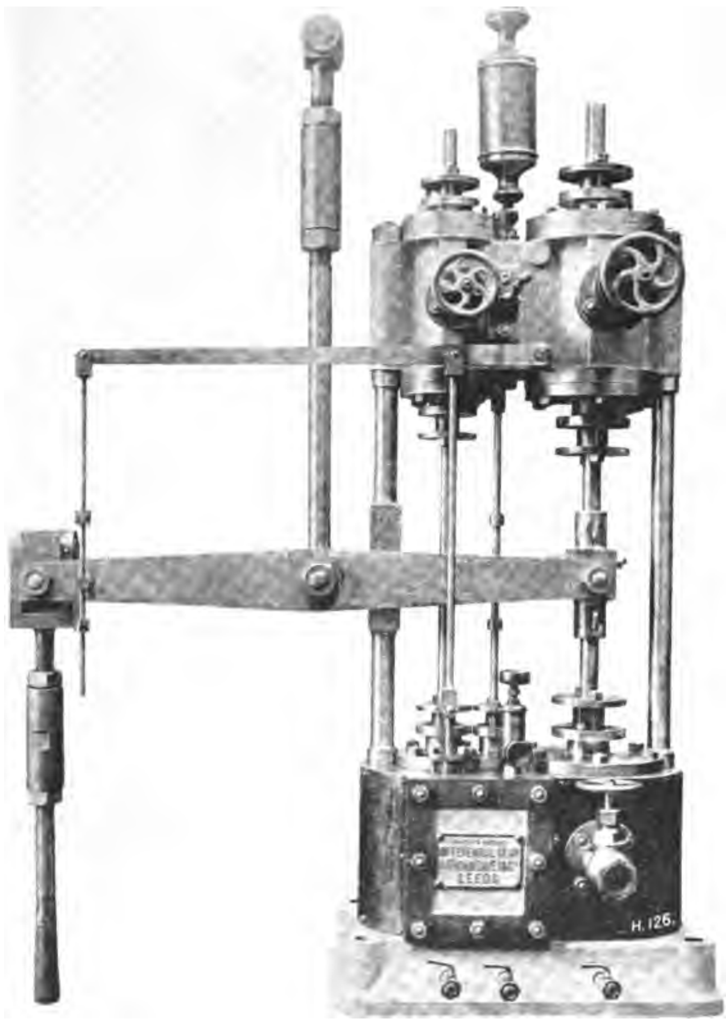


FIG. 33.—Standard Differential Gear.

quired—a point of considerable importance where wet and dry seasons prevail.

In erection this engine does not differ materially from an ordinary horizontal, but being direct acting, the centre line of the pump rods and bob will also be the centre of the cylinders. The condenser usually stands by the side of the main engine, the air pump being worked by a rod from the axle of the quadrant. As the length of the stroke is not controlled by a crank, catch wings are provided on the pump rods and bumper beams under the quadrant.

These differential engines have been selected for what is probably the heaviest installation of pumping machinery on any gold-mine in the world (the Tasmania gold-mine). The three engines each have high-pressure cylinders 50 in. in diameter, low-pressure cylinders 108 in. diameter; stroke, 10 ft.; working pressure, 150 lbs. per square in. To each engine are connected main rods 22 in. sq., operating four plunger pumps 20 in. diameter by 10 ft. stroke, and lifting a vertical height of 500 ft. each. The complete installation is to be capable of raising 8,000,000 gallons a day from a depth of 2,000 feet.

The following hints on working the engine and adjusting the valve gear are extracted from the instructions furnished by the makers:—

Before starting, open all drain cocks and warm the cylinders by admitting a little steam; all drain cocks should be connected together to a common pipe leading to the condenser, otherwise the low-pressure cylinder will not be drained.

The differential gear should be worked for a few strokes by hand, by means of the lever provided for the purpose. When the gear works freely, the engine may be started and reversed by hand for a few strokes; then connect the reversing motion and run the engine on a short stroke until full load and vacuum are on.

See that the cataract does not work too fast. Should it do so, it will not control the engine, and the supply of steam will have to be regulated by the stop valve, which is extravagant in steam and unsafe in case of sudden loss of load. The cataract cylinder must be full of clean, preferably condensed water; the feeder must be attended to and kept constantly full.

If the main piston works too near one end of the cylinder, the position of the expansion slide can be varied by the adjusting rod with right and left hand coupling. In addition, there is generally an adjustable cross-head on the expansion valve spindle by which the position of the slide can be varied.

When trip gear is fitted to a large engine, the springs should not be too tightly compressed. The springs and adjusting plug ought to be so sensitive that a moderate increase in the speed of the engine will cause the valve to trip.

Where circular compression valves are provided on the high-pressure cylinder, it is usually best to adjust them to compress the steam at three-

quarters stroke at starting; altering them gradually to compress later in the stroke after the engine has fairly started and obtained full vacuum. The exact position best for each engine can only be ascertained by trial.

To lengthen the working stroke, lower the die in the cut-off lever. To shorten the stroke, raise the die in the cut-off lever.

When the required length of stroke is obtained, move the tappets to position for reversing the gear.

To reduce the speed of the engine, it is best to make pauses of longer duration between strokes, by screwing in the pausing cataract plug; do not alter the speed of the main cataract.

Connections.—The motion derived from the engine being horizontal, it must be altered to suit the angle of the mine shaft; this is done by the Tee bob or quadrant, the upper end of which is connected to the pumping crank by the sweep rod. For heavy lifts quadrants are preferred, and are constructed of steel plate, sometimes stiffened by a timber filling.

The wrought-iron bob at the Thames Hauraki Mine weighs 22 tons, and transmits the geared strain of a compound condensing engine, with cylinders 30 and 60 in. in diameter by 5 ft. stroke. In ordinary practice the principal members are timber beams, trussed with wrought-iron bridles; the sweep rod is attached to the top of the upright, or king post, and the bridles transmit the strain to the pin at the end of the queen post. In vertical shafts these two members stand at right angles to each other; in incline shafts the queen post, at half stroke, will always be at right angles with the underlie of the shaft.

Sometimes bobs are shored up with timber from the pumping nose to the top of the king post; this ought not to be necessary, as the pump rods should always exceed the weight of water to be lifted by the force pumps, and the strain between these two points is therefore tensional.

The balance in the box should be equal to half the weight of the pump rods; so that on the up stroke the engine lifts half the weight of the rods and on the down stroke raises the balance weights, the pump rods being then balanced by the rising water and friction in the pipes. In deep mines the mere weight of the rods is a considerable strain on the upper members, and is relieved by balance bobs placed at intervals of a hundred fathoms or so in the shaft; these serve to balance, or take up, any excess in rod weight beyond that required for working the pumps.

Angle bobs are introduced at points where the shaft deviates from its usual direction. At half stroke each limb of the bob will stand at right angles to the line of rods to which it is connected.

The pin on the king post is level with the pumping crank shaft, and as this post is 10 ft. or more high, the bob is usually placed in a pit, and the main bearings fixed some 5 or 6 ft. below the surface. This arrangement is necessary to keep the engine centre within reasonable distance of the ground.

When lifting pumps are employed, the first piece of main rod often rests on the bob, instead of hanging from it; by means of a set-off on this "sky-pole," the water is raised above the level of the bob and delivered at surface.

Fig. 34 is a plan of a bob loading and pit, showing the bob in position; the line A B is seldom set out from the centre of the pumping compartment, as by placing the bob on one side more room is left for the column. The crow and bolt holes in the loading are laid off from the centre C D; this line being measured from the centre of the pump rods, after allowance has been made for the vibration of the bob nose, and squared from the line A B.

Fig. 35 is an elevation of the same bob, suitable for a pair of 18 in. by $3\frac{1}{2}$ ft. geared engines with a pumping stroke of 6 ft. The sectional view of the balance box shows how the frames at the front and back ends are arranged. In assembling the bob, care should be taken that the three main pins lie in the same horizontal plane and are not twisted with each other; the bridle ends under the balance box are tightened until a slight camber is given to the main beam.

The main rods forming the connection between the bob and pumps are seldom hung in the centre of the pumping compartment. If placed on one side, more room is left for the columns, or rising main. They are composed of lengths of wrought-iron or timber rods, the latter material being more generally used; with the exception of those attached to direct-acting engines, their total weight must exceed that of all water lifted by any forcing pumps. Their diameter is seldom constant throughout the whole length, but is gradually diminished as depth is attained. When the rod is made of pitch pine or wood of similar weight, the general rule is to let each side of the square baulk be not less than the diameter of the force pump attached; naturally, all weight added in the form of bolts, strapping plates, and connections, is also effective. In order to avoid frequent joints, the longest baulks that can be obtained and conveniently handled are selected; care is taken that the timber is sound, free from shakes and flaws. At the joints, the ends of the baulks are squared, butted together, and secured by strapping plates and bolts, four plates to each joint.

To prevent bending under the compression due to superincumbent weight, the main rod is stayed at intervals of 25 to 30 ft., thin planks being bolted to the four sides to protect them from wear in their passage through the stays. See A, Fig. 36. In case of heavy wear on any particular stay, the stay itself is protected by a piece of round iron let into the cross bar. Catch-wings are bolted to the rod at intervals, so that in case of breakage the weight of the rod would be taken by the bearers below. See B, Fig. 36.

In incline shafts it is necessary not only to support the rod against

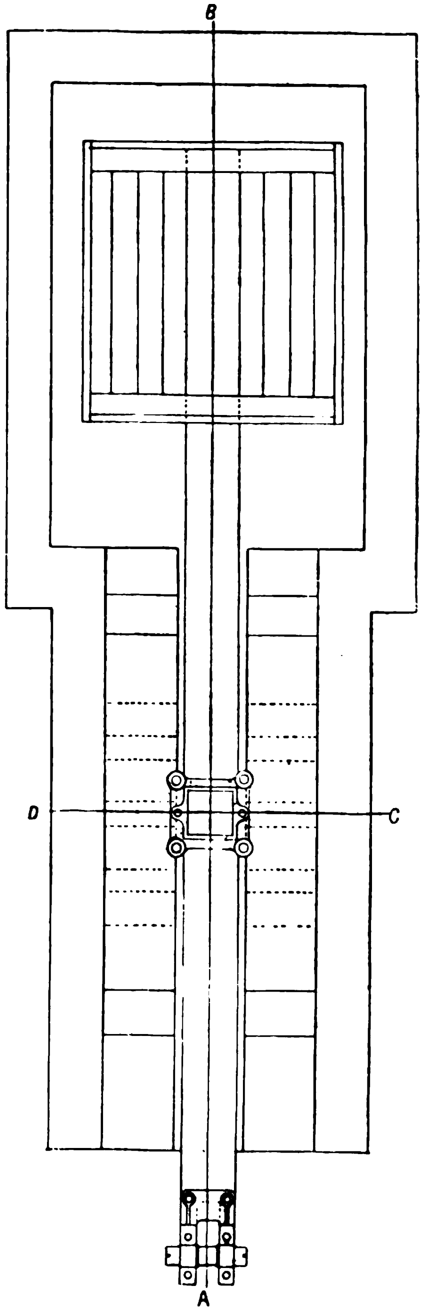


FIG. 34.—Plan of Bob.

bending, but to take up its weight, and rollers therefore take the place of stays; supports are always placed more closely together when the rod is worked by a double-acting engine, such as the Hathorn Davey.

Pit Work.—The pumps attached to the main rods are generally on the Cornish system, in which high pressures are avoided by pumping in stages. Each complete set of pumps is known as a "lift," and the distance between them is about 240 ft.; each lift discharges into a cistern placed 240 ft. above it, whence the water is again drawn by the lift above. Each pump is of the ram or force type, the water being lifted by the displacement of a "pole"; but the lowest lift, having no fixed position in the shaft, is always a bucket, or drawing lift.

Although the usual height of a plunger lift is 240 ft., this distance may be increased or diminished in order to enable the pump to deal with the water coming from any particular level or cross-cut. Still it is not advisable to greatly exceed this limit, as the large valves, or "clacks," of the Cornish pump are suited only to moderate lifts, and at higher pressures close with considerable shock. This trouble is augmented as the speed is increased, and about twelve strokes a minute is the maximum for this class of pit work.

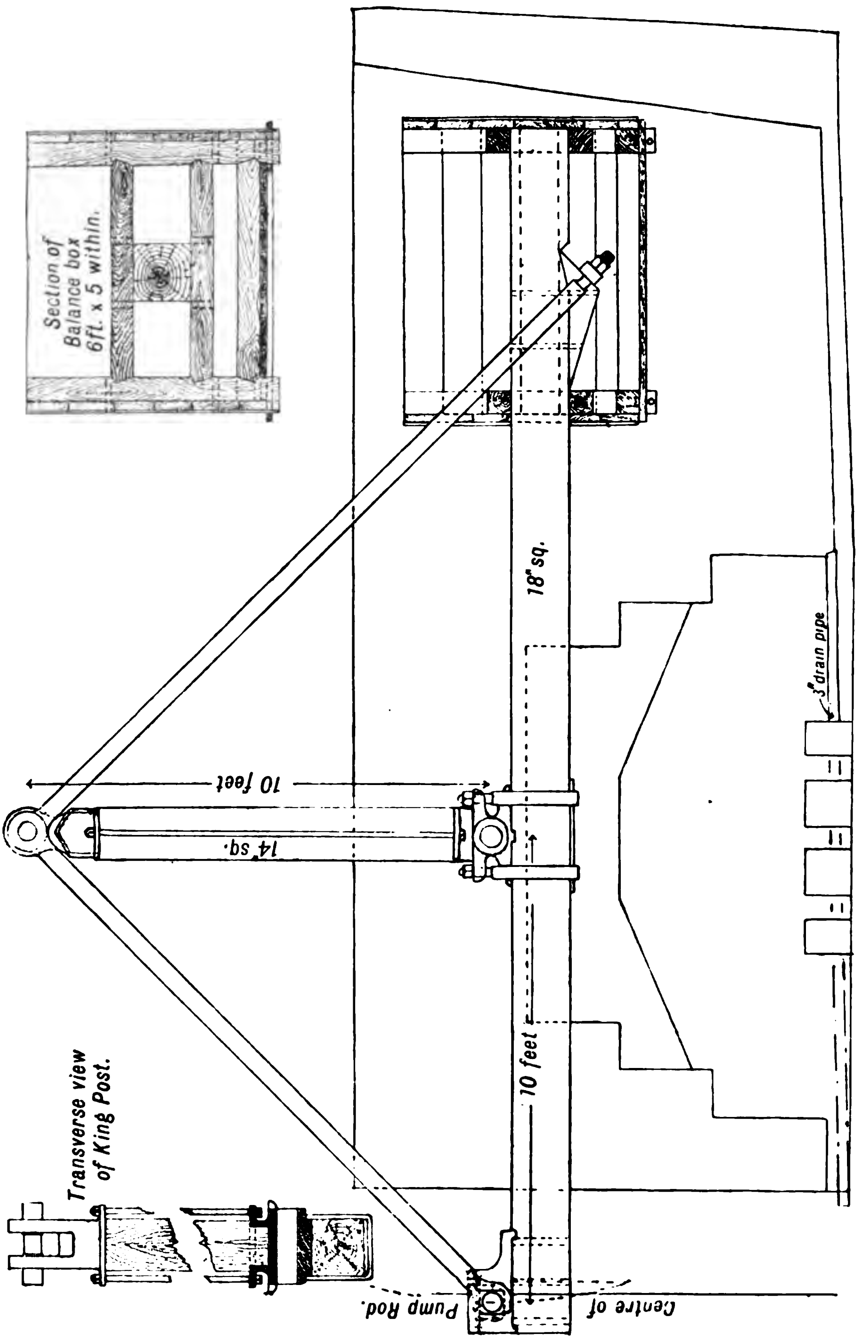


FIG. 35.—Elevation of Pumping Bob.

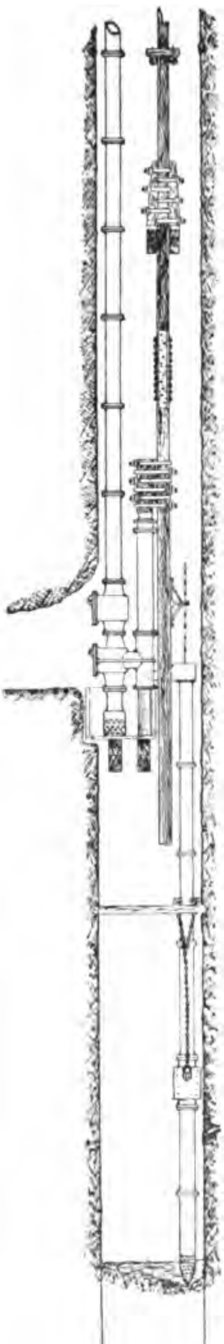


FIG. 36.—Arrangement of Pit Work in Mine Shaft.

Fixing a Plunger Lift.—To economise room each pump is almost invariably fixed on one side or the other of the main rod, and the bearers on which it rests therefore stand parallel with the dividings of the shaft. These bearers will be so placed that the cistern in which the pump stands will be slightly below any adjacent mine level or cross cut, so that any water making at that depth may be led direct to the cistern instead of finding its way farther down the shaft.

Having determined on the position, the hitches in which the bearers are to rest may be made; preferably they are cut out of the solid rock with moyles and gads. In very hard rock, holes a few inches long may be bored and fired with half or a third of a plug of dynamite, the greatest care being taken not to shatter the face of the rock. Naturally, the hitches will not be reliable if cut in an overhanging shelf, nor unless the ground immediately beneath them is sound. The depth to which it is necessary to cut is a matter depending more on the soundness than the hardness of the ground; in country thoroughly sound, free from seams and slips, 2 in. is sufficient, since the weight is taken more by the ends than by the area on which the bearer rests.

The hitches being squared up and levelled with each other, the bearers may now be cut to length and put in, one at a time; each is wedged tightly at one end, first with wooden wedges, then with thin iron ones. If this wedging is thoroughly done, the slight swelling of the timber with the dampness makes the bearer firm as the rock itself. The size of the bearers depends on the weight of the lift and the width of the shaft, or distance between points of support; usually there are three, placed one over the other, each being the same size as the main rod.

The cistern is now placed in its position on the bearers; in it rest the suction pipe, or "windbore," which supports the weight of the rising main, and the dead end (often a piece of timber), which supports the pole case. On these rests the **H** piece, which connects the pump to the rising main, and contains the bottom clack; the pole case is bolted to the side of the **H** piece nearest the main rod; on the

opposite side the top clack piece is fixed. On the top clack piece comes the rising main, and if the pump is being fixed near the bottom of the mine, the lowest pipe in the rising main is usually bored as a working barrel, with a diameter slightly smaller than the rising main pipes.

By this means, should the plunger pump give out while drowned or submerged, it can be converted into a drawing lift. This is done by lowering a drop clack into a seating prepared for it on the top clack box, and by lowering a bucket into the working barrel at the foot of the rising main; the pump may then be worked as an ordinary bucket lift until the plunger is redeemed. At its upper end the pole case is steadied by a piece of timber thrown across the shaft, and the rising main is steadied and supported by stays, placed at intervals of about 50 ft. The pole, or plunger, is cast hollow, and turned parallel on the outside. It must be carefully fitted to a timber stocking-piece about 6 ft. longer than the pole itself. The upper end of the stocking, where it projects from the pole, is square in section; the lower end is secured to the pole, first by wooden, and afterwards by iron wedges. A leaky stocking-piece is an awkward matter to rectify; on the other hand, it is possible to wedge up too tightly and split the iron casing.

The complete pole, with its stocking, is now lowered into the case, and a distance piece prepared corresponding in thickness to the interval, or space, between the stocking and the main rod. Before connecting the pole, the total depth of the case should be measured and noted, also the depth from the gland to the lowest bored part of the stuffing-box. This latter distance is now measured off on the pole from its lower end, and marked on its side; when this mark is level with the top of the stuffing-box gland the pole may be connected, provided the rods are at their highest point in the stroke. If the rods are at their lowest point, the pole is lowered into the case the same amount, plus the length of the pumping stroke. The connection is made by staples and glands, as shown in Fig. 36. In attaching a pole to rods operated by a crank with variable stroke, allowance must be made for possible lengthening of the pumping stroke.

The clacks are faced with leather, and their seats made tight in the boxes by a binding of tarred blanketing; chains and screw shackles are hung over the doors to take their weight when open for adjustment of the clacks. The general arrangement of all the working parts is illustrated in Fig. 36.

The Drawing Lift.—The lowest pump in the shaft is always a bucket or drawing lift, this type being fixed in no permanent position like the plunger, but being free to follow the increasing depth of the shaft. It consists of a windbore, clack piece, working barrel, and rising main; in this case the rods attached to the bucket are placed within the rising main.

The windbore of the drawing lift rests on the bottom of the shaft, and as the depth increases the lift is lengthened by adding pipes at the top. To provide for the varying length of lift required, short pipes, known as matchings, are supplied. Thus the pipes added to the lift would be successively 3, 6, and 9 ft. long. In order that the rods may maintain their relative length to the lift, their upper end terminates in a pin-plate; and by engaging successive holes with the set-off, the rods may be lengthened until the depth is sufficient to admit a short rod being added. When a telescopic windbore is used, the weight no longer rests on the bottom, but must be taken up by yokes around the top of the lift. See Fig. 36. When a door piece is not provided for convenience in changing the bucket, the whole length of rods must be drawn from the lift each time the bucket is changed. Spare buckets and clacks are always kept on hand.

Fig. 37 shows a complete bucket for a sinking lift, the working barrel being shown in section. A is the prong, B the form, C the leather gearing, D the ring, G and H the gib and cotter. It may be noticed the exterior of the form and interior of the ring are portions of a cone having its apex at E. This point E is the centre from which the bucket gearings are marked off, usually a wooden template is cut, as shown by the dotted lines. The length of the gearing must be such that two ends meet neatly when placed around the form.

The ring is then driven on, and, tightened by the cotter, keeps the gearing firmly in position. The height the gearing is allowed to project above the form is an important point, and depends chiefly on the condition of the working barrel, though it also increases slightly with the diameter. For moderate size pumps, from 9 to 12 in. diameter, three-quarters of an inch is sufficient. This may be increased to $1\frac{1}{8}$ or $1\frac{1}{4}$ in. when the working barrel is worn and no longer parallel in its bore. Any additional height beyond that actually sufficient only increases the friction of the pump and adds little to the life of the gearing.

The appearance of the water, as delivered at the head of the column, is an indication of the condition of the pump. Thus bubbles of air show a leak in the suction pipes. Frothy water, sometimes violently ejected, is caused by air being drawn through the windbore; the pump is "in fork," the suction holes no longer submerged. The bottom clack is leaky if the water does not remain level with the top of the column while the rods make their downward stroke. Water rising and falling with the motion of the bucket, but not being pumped, tells the pitman the bottom clack is trigged up. In the opposite case, when water remains at a constant height and receives no motion from the pumping strokes, something is amiss with the gearing or clack of the bucket.

Jack Head Pumps.—There is another variety of pump also worked by rods, and known as the "jack head." It is a drawing lift with a cover

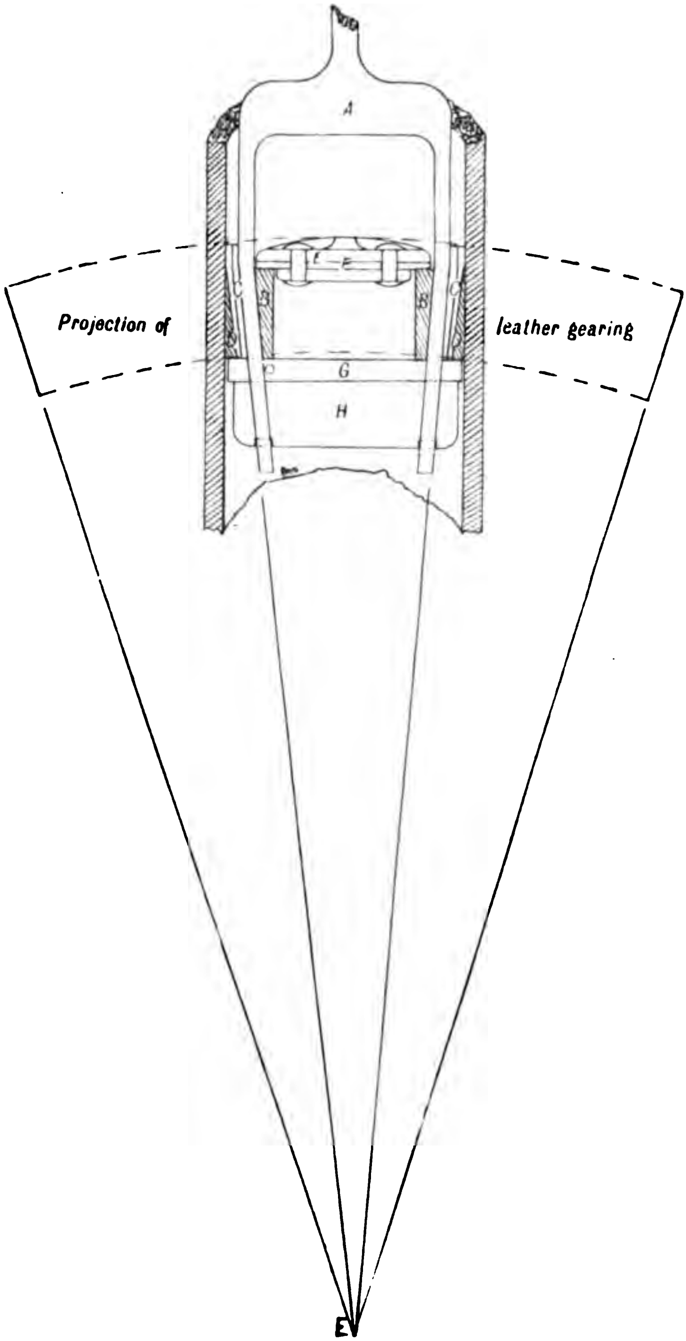


FIG. 37.—Bucket and Prong for Drawing Lift.

over the working barrel provided with a stuffing-box through which the rod works. As the bore of the barrel and the centre of the stuffing-box must be aligned with the rods, this form of pump must be almost as carefully fixed as the plunger lift, and since it has not the corresponding advantages, there is little justification for its use.

Station Pumps.

Station pumps are permanently fixed in position underground, and driven either by steam, compressed air, electricity, or hydraulic power. When once submerged most of them are useless, hence, as a matter of precaution, they are generally duplicated, and are not placed in position until considerable ground has been taken out around them, and a large lodgment for water secured.

The foundations required depend on the motive power and capacity of the pump. An ordinary steam pump may be laid on any convenient bearer, but it is not advisable to push this advantage too far, and, unless properly secured to its foundations, the jar of constant stroke reversal soon causes leaky joints and connections.

The more complex forms require special chambers, concrete foundations, and are secured by anchorage bolts let into lewis holes either in the concrete or solid rock.

Station pumps are generally worked on a different system to those operated from surface. The latter are kept constantly at work, being regulated in the engine room to the speed required to cope with the coming water. Station pumps, being generally of ample capacity, are seldom worked continuously. The water is allowed to accumulate in the mine, and rapidly sent to surface by a few hours' pumping. This plan answers well enough when the water is not heavy and there is ample lodgment room, but few, if any, really wet mines are drained entirely by this method.

A feeling exists among many mining men that delicate, high-speed machinery is out of place when permanently fixed underground. They want to know what the repair and renewal bill will amount to in five years should skilled attendance not be available, and prefer the simplicity of the Cornish system, in which ordinary running repairs can be done by most intelligent miners. The same man who could change a bucket or tighten a blowing pole might, with the best intentions, ruin a high-speed motor. In mines where the water is not a serious item, these pumps certainly possess advantages. They occupy less valuable room in the shaft, are suitable for lifts of a thousand feet and over, and offer a choice of alternatives as regards motive power.

On the other hand it must be admitted that the noise made by all forms of geared pump is greatly increased by the confined surroundings, that rapidly moving parts require constant lubrication and attention, that solid foundations are necessary to absorb the vibrations due to frequent reversal of motion, and that, for safety's sake, the installation should be duplicated.

The Riedler Pump.—The principal features of this pump are the valves, and the mechanical arrangements for closing them at the end of the pumping stroke. There is but one valve for the suction and one for the delivery. Each is a circular bronze casting fitted with inclined vanes which ensure a partial rotation at each pumping stroke, and secures even wear on both valve and seat. Neither of these valves is in any way controlled by springs. At the commencement of each stroke a free and automatic lift of 1 or 2 in. is allowed; while, at the end of the stroke, the valves are closed by rocking gear worked from the crank shaft. As the result of the ample valve area and lift provided, the speed of the water in the passages is reduced to a few feet a second; while the positive closing action secures remarkable freedom from slip, even when running at very high speeds. It is owing to the mechanical valve-closing that speeds of 300 and 400 pumping strokes a minute are not only obtainable but run with high mechanical efficiency; while the speed allows a small, light pump to be of relatively large capacity.

For station work two rams, generally of different diameters, are mounted tandem and driven by a crank and connecting rod, the crank shaft being worked by any rotary motor. The arrangement may be either horizontal or vertical, the duplex form being particularly suitable for this work, as one side can be held in reserve, and both coupled up in an emergency.

This pump may be driven by belt, gearing, or ropes, but the high speed renders it particularly suitable for direct connection to Pelton wheel or electric motor. In the latter case shunt winding is preferred, and as the pumping is done by numerous strokes of small capacity, the load on the motor is uniformly maintained, and a light torque required.

The following test of an electrically driven Riedler pump was made under working conditions underground. The two rams were each 6⅝ in. in diameter by 9 in. stroke, and driven at 400 strokes a minute by a geared electric motor of 75 H.P., making 500 revolutions a minute. The current actually supplied at the pump, 101 ampères at 459 volts; the water pressure on the delivery valves, 195 lbs. per square inch.

Under these conditions 380 gals. of water were delivered a minute, or over 90 per cent. of the theoretical displacement; while the efficiency of the pump and motor was 85 per cent. of the power supplied.

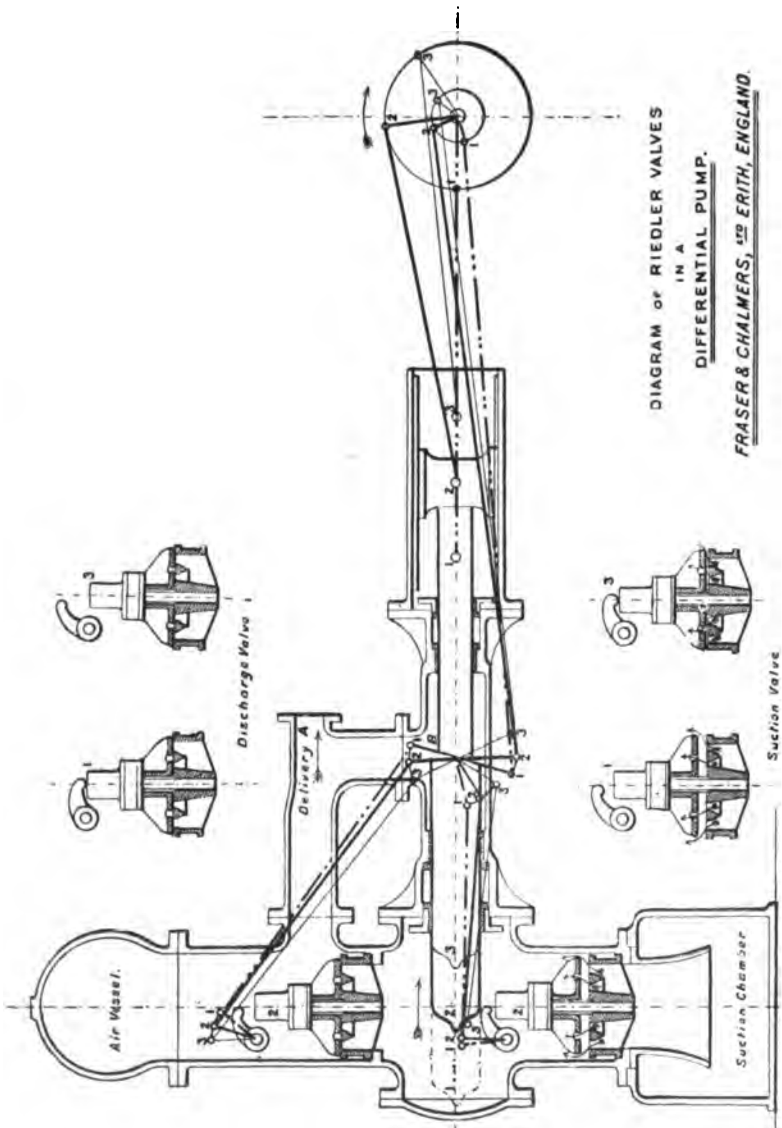


FIG. 38.—Riedler Differential Pump (Section).

STANDARD POWER-DRIVEN RIEDLER PUMPS, SINGLE DIFFERENTIAL PLUNGER.

Gallons per Minute.	Head.	Diam. of Large Plunger.	Diam. of Small Plunger.	Stroke.	R.P.M.	B.H.P. of Motor Required.	Suction Pipe Diameter.	Delivery Pipe Diameter.
	Feet.	Inches	Inches.	Inches.			Inches.	Inches.
68	300	3 3/4	...	12	150	8	4	3
	600	3 3/4	...	12	,,	15	,,	,,
	900	3 3/4	2 5/8	12	,,	22	,,	,,
	1,200	3 3/4	2 5/8	12	,,	29	,,	,,
100	300	4 9/16	...	12	,,	12	4 1/2	3 1/2
	600	4 9/16	3 1/4	12	,,	22	,,	,,
	900	4 9/16	3 1/4	12	,,	32	,,	,,
	1,200	3 15/16	2 3/4	16	,,	43	,,	,,
	1,5c0	3 15/16	2 3/4	16	,,	53	,,	,,
135	300	5 1/4	...	12	,,	15	5	4
	600	5 1/4	3 3/4	12	,,	29	,,	,,
	900	4 9/16	3 1/4	16	,,	43	,,	,,
	1,200	4 9/16	3 1/4	16	,,	57	,,	,,
	1,50)	4 9/16	3 1/4	16	,,	71	,,	,,
175	300	6 1/16	4 1/4	12	,,	20	6	4 1/2
	6 0	5 1/4	3 3/4	16	,,	38	,,	,,
	900	5 1/4	3 3/4	16	,,	56	,,	,,
	1,200	5 1/4	3 3/4	16	,,	74	,,	,,
	1,500	5 3/4	3 5/8	24	120	92	,,	,,
265	300	6 3/8	4 1/2	16	150	30	7	5
	600	6 3/8	4 1/2	16	,,	58	,,	,,
	900	5 7/8	4 1/8	24	120	85	,,	,,
	1,200	5 7/8	4 1/8	24	,,	112	,,	,,
	1,50)	5 3/8	4 1/8	24	,,	139	,,	,,
330	300	7 1/8	5	16	150	37	8	5 1/2
	600	7 1/8	5	16	,,	71	,,	,,
	900	6 1/2	4 5/8	24	120	105	,,	,,
	1,200	6 1/2	4 5/8	24	,,	139	,,	,,
	1,500	6 1/2	4 5/8	32	90	173	,,	,,

The above table gives some of the sizes made by Messrs Fraser & Chalmers, sole manufacturers of this pump for Great Britain and the Colonies.

The Multiple Ram Pump, placed horizontally or vertically, and driven by electricity, compressed air, or both, is extensively used for station pumping. Machine-cut spur gearing is interposed between the counter-shaft and crank-shaft from which the rams are driven, the ratio of gearing being four or five to one. In all station work, the height to which the water is to be raised is not divided into lifts, as in the Cornish system, but the capacity of the pump is proportioned to the power applied, so that the water is raised to surface at one lift. As the vertical height often exceeds a thousand feet, the pressures are severe, and the ram pattern is preferred to the piston, or double-acting type. To secure an even turning moment on the shaft, three rams are usually driven by cranks set at an angle of 120° with each other. When arranged horizontally, the ram cases are

bolted directly to the base-plate carrying the shafting. This is shown in Fig. 39, an illustration of a treble ram pump, by the Sandycroft Foundry Company, Chester. The design permits easy access to all the working parts, especially the valves and packing glands. The horizontal arrangement occupies rather more room than the vertical, in which the ram cases are bolted to the base-plate, and the crank shaft carried by overhead girders supported on columns.

The following table gives the sizes, capacities, and power required for varying lifts in some of the standard arrangements of treble ram pumps:—

Diameter of plungers, in inches	3	4	4	5	5	6
Stroke, in inches	4	4	6	6	8	8
Diameter of pipe connections, in inches—						
Delivery	1½	2	2	3½	3½	4
Suction	2	2½	2½	3½	3½	4
Diameter of pulleys, in inches	16 × 4	18 × 4	20 × 4½	26 × 5	30 × 5	33 × 6
Average revolutions of crank shaft, per minute	50	50	40	40	40	40
Gallons of water delivered, per minute	14	25	30	50	66	95
Brake horse-power required at 50 revolutions—						
Total lift, 50 ft.	0.31	0.61	0.74	1.16	1.55	2.22
,, ,, 100 ,,	0.69	1.23	1.49	2.32	3.10	4.44
,, ,, 150 ,,	1.04	1.85	2.23	3.48	4.65	6.66
,, ,, 200 ,,	1.39	2.47	2.98	4.64	6.20	8.88
,, ,, 250 ,,	1.74	3.09	3.72	5.80	7.75	11.10
,, ,, 300 ,,	2.08	3.70	4.47	6.96	9.30	13.32
,, ,, 350 ,,	2.43	4.32	5.21	8.12	10.85	15.54

The various forms of direct-acting pump are often used for this purpose, and when driven by steam, are compounded and fitted with condensers.

Station pumps may also be operated by hydraulic power, either supplied through an accumulator, or directly from the pump at surface to that underground. In the latter case the pump underground keeps time and stroke with the motor at surface, the hydraulic supply circulating between the two, and requiring an up and down pipe for the purpose. Very little use is made of hydraulic power in mining, probably because, unlike electricity and compressed air, it is not readily applicable to purposes other than pumping.

In mountainous districts it is often possible to obtain a supply of water at high pressure for a very moderate outlay, and a jet is capable of raising water without the intervention of any pumps. The arrangement is on the principle of the injector, the hydraulic supply is piped beneath the water to be pumped, and a jet directed vertically into the open foot of the delivery column. Unfortunately this simple plan cannot drain a shaft or winze to the bottom, though the deepest level in the mine may be drained in this way, provided there is a good sump below it. At the Colmstock Mine the

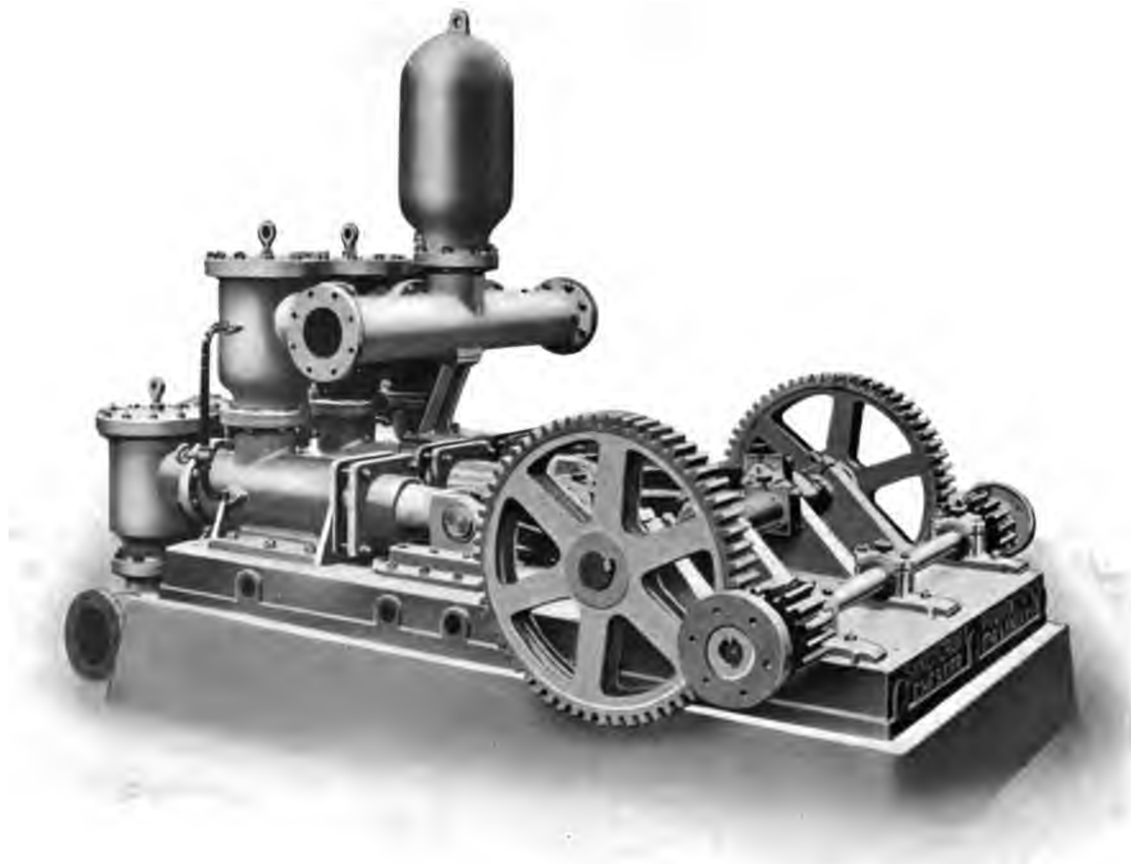


FIG. 39.—Horizontal Three-throw Single-acting Plunger Pump for Station Work.

[To face p. 104.

jet used is $1\frac{1}{8}$ in. in diameter, and issues under a pressure of 870 lbs. per square inch at a velocity of 340 ft. per second. Under these conditions a hydraulic supply of 1,450 gallons a minute raises 2,600 gallons of mine water a height of nearly 200 ft. Without increasing the pressure, a much greater lift could be made with a corresponding diminution in the quantity lifted. The intake and jet are situated 70 ft. below the surface of the water to be pumped. This depth is not essential to the working of the process, but serves to check the vibration caused by high pressures.

Air Lift.—Compressed air offers another means of raising water without the use of a pump, but here again the intake must be well submerged, as the principle involved is that a column of mixed air and water is lighter than an equal column of water only. The inlet being lowered about 20 ft. below the water to be raised, compressed air is admitted at the bottom by a pipe which may be either inside or outside the rising main. The submerged 20 ft. of pipe becomes filled with mixed air and water, and is forced upwards by the greater weight of the unmixed water outside the delivery pipe. About 70 ft. is the limit for one lift, the exact height depending on the air pressure and the submersion of the intake. Naturally the quantity of water delivered with any given air pressure decreases as the height of lift is increased, but the whole arrangement is so simple as to be worthy of more extensive use. There are no moving parts, and consequently no wear, even when dealing with gritty water; no special jets are required, the whole thing can be made from a few lengths of piping, and the cost of the compressed air used is often less than ½d. per thousand gallons of water raised.

Direct-Acting Pumps.

Direct-acting pumps may be divided into two classes, according as the steam valve is positive or not positive in its action. Positive pumps are fitted with a crank shaft and flywheel, and the valve is worked by an eccentric in the usual way. On account of their extra weight and space occupied, they are seldom used for any purpose but boiler feeding.

In non-positive pumps the valves are actuated by the same motive power, steam or compressed air, that works the pump; they are held in stock at most mining centres, and are therefore easily obtainable. They are light, portable, easily and quickly erected, will work in almost any position, and require no special foundations. These advantages render them particularly suitable for preliminary work and temporary use; under other conditions a more economical type might be desirable.

They may be worked by steam or compressed air; the latter is more searching, and requires a pump in thorough order and adjustment. When

steam is used, condensed water assists in keeping the working surfaces tight, while air gives no such assistance. Hence it follows that a pump may work under steam which will not be satisfactory under air pressure.

Their steam consumption is considerable because, (1) there is no period of expansion in the stroke, full steam pressure being on until the exhaust is opened; (2) as the length of stroke is not regulated by a crank, its variable length necessitates ample clearance at the cylinder ends; (3) they are generally run with wet steam and under most disadvantageous conditions.

In addition to its innate shortcomings, this pump is often unfairly treated, being run at its highest speed and allowed to work for long intervals at this rate with a minimum of attention and lubrication. Then again, it is blamed for not doing impossibilities. Being a pump it is considered capable of lifting to any height anything that will flow through a pipe; and a low service pump, with steam and water cylinders nearly equal in diameter, is condemned because it does not raise water 200 ft. with steam that was 60 lbs. at the boiler, a quarter of a mile away. Or it may be condemned because not adapted to the particular work required of it, as was the case with a certain Duplex pump, which had no packing in the water end, only brass plungers working through bored bushes. This arrangement answered so well, and required so little attention at surface that the pump was given the post of honour, sent underground, and used for shaft sinking. Under the altered conditions it became a constant source of worry and delay, the gritty water cut the plungers and bushes to pieces in twelve days, and their life never exceeded a fortnight.

Selecting a Pump.—In selecting a pump for any particular duty the diameter of the steam and water cylinders must be in proportion to the lift required and working pressure available. The two ends of the pump form an equation as it were, and the area of the steam cylinder multiplied by the working pressure must equal the area of the water piston multiplied by the water pressure. It may be worth while to take an example and run through the figures to see how these sizes are determined.

Suppose it is required to raise 10,000 gals. of water an hour a vertical height of 462 ft., the working pressure on the steam piston being 60 lbs. per square inch. In the first place, to provide for slip and contingencies, we add 30 per cent. to the quantity of water to be raised, and provide a total of 13,000 gals. per hour, or 217 gals. a minute.

This will require a displacement of 60,967.59 cub. in.; if the pump is to run at the rate of 50 strokes a minute, there must be a displacement of 1203.35 cub. in. per stroke; and if the pumping stroke is to be 18 in., then 1203.35 divided by 18 gives 66.85 sq. in. as the area of the pump piston. This means a diameter of $9\frac{3}{16}$ in., so we fix on $9\frac{1}{4}$ in. as the size of our plungers.

The pressure due to a column of water 462 ft. high will be 200 lbs on the square inch, and this multiplied by the area of the plunger (66.85 sq. in.) gives a total resistance of 13,370 lbs. to be overcome by the steam piston. As the steam pressure is 60 lbs., we get 13,370 divided by 60, or 223 sq. in., as the area of the steam piston; this corresponds to a diameter of 16 in., but to overcome the water friction in pipes and passages, an 18-in. steam cylinder would be provided.

When dealing with gritty water, the plunger, or ram, pattern is preferable; the packing is then external, any leakage visible, and can be rectified while the pump is running. This type is, however, heavier than a double-acting pump of equal capacity.

When a piston pump is used on gritty water, packing lasts longer than cup leathers, but causes more wear in the working barrel, as particles of grit become embedded in the fibrous packing. The water cylinder should therefore be fitted with a removable lining, not a practically irremovable one, forced into its place by screws or hydraulic power, but fitted with flanges at the end and bolted into position.

It must be noted that, on account of the unbalanced weight of the steam valves, some of these pumps only work well in the position for which they were designed; a horizontal pump may not be satisfactory if hung vertically, and *vice versâ*. Those in which the steam valves are partly actuated by the movement of the piston rod lend themselves more readily to alterations of position than others having valves actuated solely by steam or air.

If clean water only is being handled, metal to metal faced valves and seats answer very well, but for underground work a yielding face is required, such as leather and the many forms of rubber; in every case these facings should be renewable without special appliances.

A pump with a long working stroke should always be chosen; under given conditions the life of the pump depends on the length of its stroke.

Fixing the Pump.—All these pumps should be fixed as closely as possible to the water they are to lift; theoretically it may make no difference whether the water is forced up the delivery or drawn up the suction, in practice it does. In extreme cases water may be drawn from 27 or 28 ft. below the suction inlet; still it is always advisable to have the suction pipes as short and direct as possible. Many of these pumps will work in any position, and may even be hung by chains in the shaft; when possible they should be bolted down to a timber bearer, and being in this way raised a foot or more from the ground, they are out of the dirt and more accessible. If used for sinking, they are placed on a platform or sollar, and thus protected from flying stones when blasting; the armoured suction hose is removed when the holes are ready for firing. In making the water connections, all elbows, trees, and quick turns should be avoided. The suction

pipe must not be smaller and may with advantage be larger than the inlet on the pump; its lower end should be protected by a strainer, and provided with a foot valve if pumping from a sump.

No additional load is thrown on the pump by increasing the size of the delivery pipe, and friction will be avoided by using a pipe a size larger than the outlet calls for. An air vessel affords an elastic cushion and protects the pump from shock at the end of the stroke; if not provided with the pump, it is easily arranged for by screwing a closed pipe into a tee inserted at the foot of the column.

In steam-actuated pumps provision for draining off condensed water must be made at the foot of the steam and exhaust pipes, and the former must be as efficiently protected as circumstances permit. One of the simplest plans is to place the steam pipe within another pipe of 2 or 3 in. greater diameter; then if the centre pipe is kept approximately in the middle of the outer one, and the space between them closed at each end, the steam pipe is not only protected from wet, but the air space between the two is a capital non-conductor of heat. When protected in this way, steam may be carried for thousands of feet. The plan is best suited to vertical pipes, horizontal ones are laid in a trough and packed around with some non-conducting substance.

The expansion of pipes under steam is about half an inch in 50 ft., but as the pipes are seldom rigidly connected at both ends, no special provision is called for. All long runs of piping in mine shafts must be stayed at intervals of about 40 or 50 ft., as a precaution against vibration caused by the intermittent action of the pump; this applies also to delivery pipes, which are affected by the pulsating current within. The exhaust from the pump, when steam is used, is piped to surface; even when condensed it seriously increases the temperature around the pump.

Particulars of Pumps.

Fig. 40 illustrates the valve gear of the well-known Tangye pump; the slide valve D is carried longitudinally on its face by the piston valve C, the spaces L at the ends of this piston valve being in communication with the steam supply. The action is as follows:—As the main piston approaches the end of its stroke, it lifts a tappet valve F, allowing the steam from the space L to exhaust through the small pipe J, to the exhaust end of the main cylinder. The piston C is now no longer in equilibrium, and is moved by the steam pressure on its opposite end, carrying with it the main slide, and reversing the stroke of the main piston.

As the reversal is effected entirely by steam pressure, the form shown in the illustration is not suitable for a vertical position; but those patterns

in which the valve piston is at right angles to the main piston work equally well in either position.

The water end is fitted with two suction and two delivery valves arranged in pairs, the delivery being above the suction and working on the same

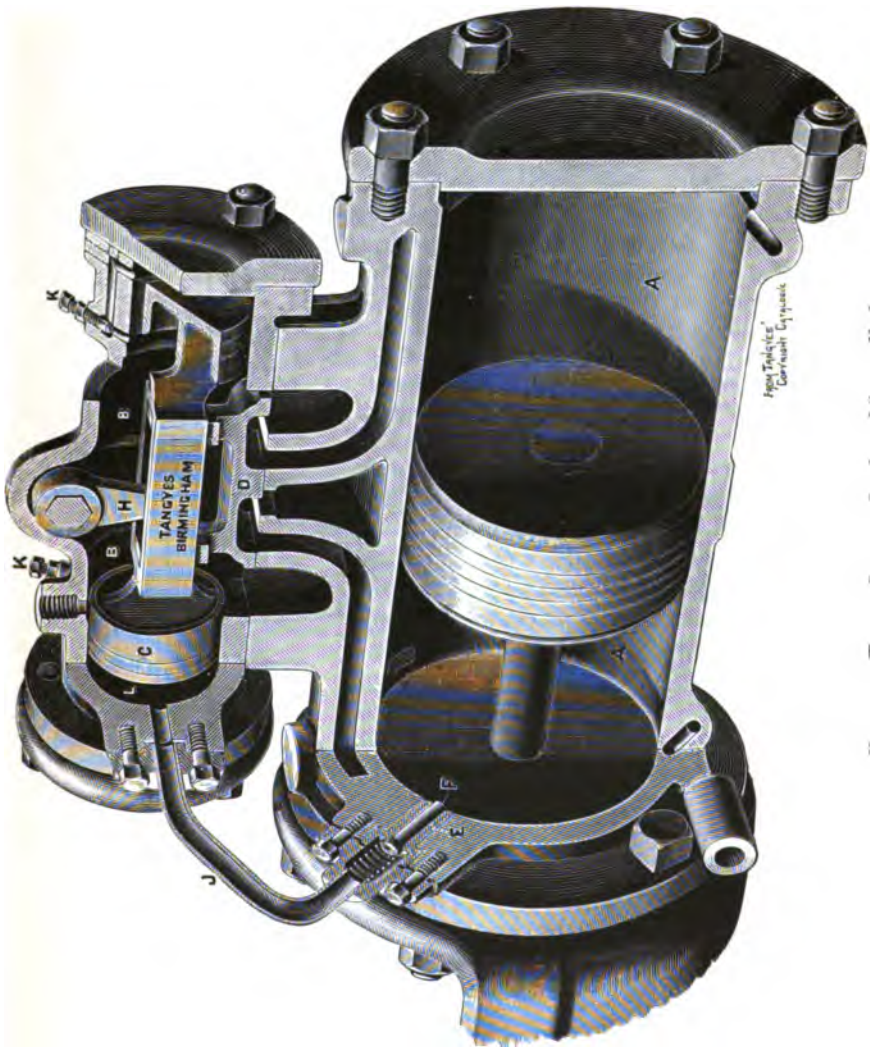


FIG. 40.—Tangye Pump. Section of Steam End.

spindles, each valve being controlled by a rubber buffer spring. These pumps are made in a large variety of sizes, and, with various types and arrangements of water valves, are easily obtainable in almost every part of the world.

The Knowles Pump has a steam valve actuated by an arm on the piston rod, which rocks a lever, one end of this lever being connected with the valve spindle; the rocking motion thus imparted to the piston valve places its ports in the position for reversal. At the end of each stroke the piston arm meets collars on the valve spindle, and the longitudinal motion given to the valve ensures the reversal of the main piston and prevents it from striking the cylinder cover. This pump does not stick even at low speeds, it reverses quietly, with almost a pause at the end of each stroke; the action is reliable, and it is as economical as this form of pump can be.

The Duplex Pump consists of a pair of pumps, placed side by side, each actuating the slide valve of the other by rocking levers worked from the piston rod. Its action may be considered as semi positive, being positive as long as both pumps are in order; but it is evident that, if the load is lost on one side, that side tends to move more rapidly, and cuts off the steam from its companion long before the stroke is completed. When compared with single pumps of equal capacity, the Duplex are heavier, occupy more room, and have twice the number of wearing and moving parts. The water ends are made in many patterns, single and double plungers being fitted as well as packed pistons; for high lifts, each valve is placed in a separate box.

In the **Cornish Steam Pumps** made by J. Evans & Sons, Wolverhampton, the slide valve is carried by a hollow piston valve; within this piston lies a second, which governs the movements of the piston valve surrounding it. As the pump piston approaches one end of its stroke, it uncovers ports admitting steam from within the cylinder to one end of the inner piston valve; this valve, in its movement, opens ports con-

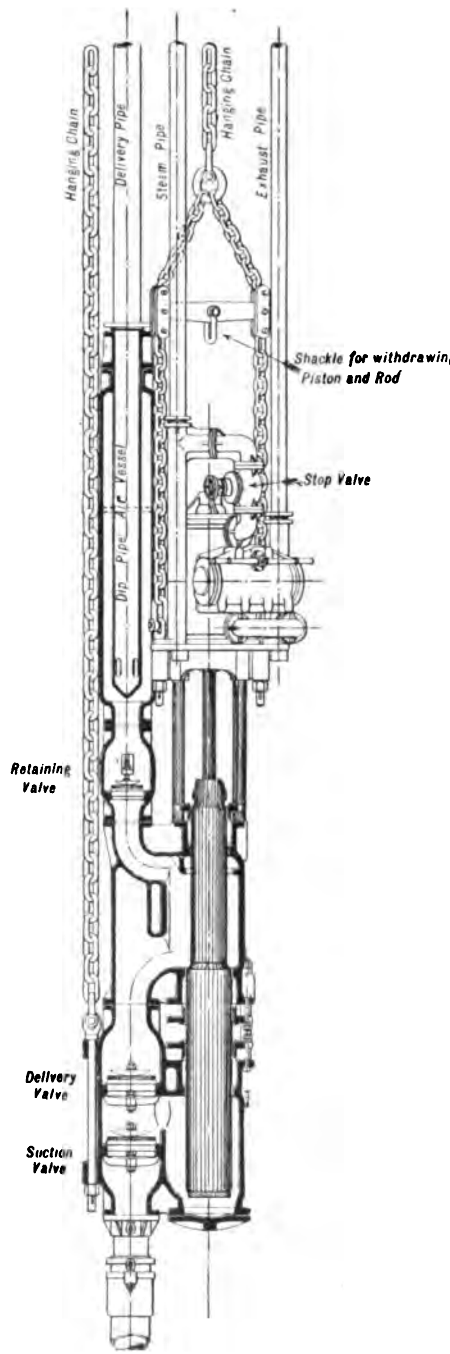


FIG. 41.—Evans's Straight-line Sinking Pump.

necting with the main piston valve, and thus reverses the pump. There are in addition some special features worthy of notice; the main ports are placed level with the bottom of the cylinder bore, enabling the cylinder to be completely drained at each stroke when the pump is working horizontally. The absence of all external and unprotected gear is also a point in their favour. In common with other pumps having a compound reversal, or reversal effected by two separate motions, there is less jar and shock at the ends of the strokes, the action is smooth and wear diminished. When required, a condenser connected to the suction can be supplied; this arrangement obviates the need of long exhaust pipes in underground work.

The water ends contain packed pistons, plungers or double plungers, the two latter forms being preferred for lifts exceeding 300 ft.

Fig. 41 illustrates the Evans Straight-line pattern pump for shaft sinking; it is suitable for heads of 600 ft. and steam pressures of 100 lbs. It will be noticed there is entire absence of all external gear likely to be damaged in the rough handling to which these machines are subjected. All parts may be easily examined without any unnecessary disconnections, and the whole pump can be suspended from the bridle chains attached to bolts passing through the cylinder flanges.

PARTICULARS OF STOCK PATTERNS OF THE STRAIGHT-LINE SINKING PUMP suitable for 600 ft., illustrated in Fig. 41. The "displacement of ram" column refers to the difference in diameter of the two parts of the ram.

Bore of Steam Cylinder.	Displacement of Ram.	Stroke.	Delivery Outlet.	Suction Inlet	Steam Inlet	Exhaust.	Approximate Weight.	Gallons per Hour, at 100 Feet per Minute.	On 50 Lbs. Steam, Water Raised to
Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Cwt.		Feet.
5	3	12	2½	3	¾	1	8¾	1,830	212
6	3	12	2½	3	¾	1	9	1,830	300
6	4	12	3	4	¾	1	12½	3,260	172
7	3	12	2½	3	1¼	1½	9½	1,830	420
7	4	12	3	4	1¼	1½	13	3,260	234
8	3	12	2½	3	1¼	1½	10	1,830	545
8	4	12	3	4	1¼	1½	13½	3,260	300
8	5	12	3½	5	1¼	1½	19½	5,100	196
9	4	12	3	4	1½	2	14	3,260	390
9	5	12	3½	5	1½	2	20	5,100	248
10	4	12	3	4	1½	2	15½	3,260	480
10	5	12	3½	5	1½	2	21½	5,100	300
10	6	12	4½	6	1½	2	31	7,340	212
12	5	24	3½	5	2	2½	30	5,100	440
12	7	24	5	7	2	2½	50	9,990	225
14	5	24	3½	5	2½	3	34	5,100	600
14	8	24	6	8	2½	3	68	13,050	234
16	8	24	6	8	2½	3	70	13,050	300
18	8	24	6	8	2½	3	73	13,050	390
20	7	24	5	7	3	3½	64	9,990	600
20	10	24	8	10	3	3½	107	20,400	300

It would take up too much space to refer in detail to all the forms and varieties of direct-acting pump, but there is, or used to be, one made in U.S.A. in which the valves were excellently arranged for mining work. The pump was known as the "Niagara," and the four water valves were placed in a chamber closed at each end by a circular door; these doors were mainly kept in position by a bolt passing through their centres, and in the smaller sizes all four valves were actually accessible by slacking up this one bolt.

The rectangular opening in which each valve worked extended right across the valve chamber, a rectangular slot in the bottom of each opening forming the water way. The brass valves were hollow squares in section, for medium size pumps being about 7 in. long by 3 in. square; each valve thus afforded four separate beats or wearing surfaces, and if one was damaged, it was only necessary to take the valve out and turn it round. For dealing with dirty or gritty water, the valves were faced with rubber; while when no spare valves were available, pieces of hard wood answered equally well. By removing both covers from the valve chamber, a file could be passed right through, and damaged seatings refaced; in fact, the water end bristled with so many good points that it is curious no English maker has ever worked on the same lines.

Adjustments.—All these pumps, having a non-positive valve motion, are liable to become tricky and uncertain in their action after having seen considerable service; the weak spot is usually easily found, in fact the simplest causes are often the most difficult to detect. This was the case with the Tangye pump, which refused to reverse, and puzzled many engineers, until it was accidentally discovered that some one had screwed a drain cock half a thread too far into the cylinder, and so prevented the piston from moving far enough to lift the tappet valve.

Usually the water end is at fault, perhaps the pump will not take its water; it is well to remember that a water pump in perfect condition is not an air pump, and on account of its large passages and clearance spaces, it may be unable to exhaust the air to the required extent. The remedy is, to displace the air by priming, or filling the barrel and valve boxes with water; a foot valve will be found an assistance in this respect, as it enables the suction pipe to be primed.

The water valves may be stuck to their seatings, and require easing and cleaning; or they may be prevented from closing by grit, dirt, or chips; their faces may be cut or damaged so as to be no longer water tight when on their seats.

The tightness of the valves may be tested by pouring water into the valve boxes, but while apparently tight they may still leak under pressure. When taking water from a considerable depth, minute leaks in the suction pipe may gradually destroy the vacuum and make the pump lose its water.

These leaks are impossible to locate and are only known by their effect; the only remedy is to change the suction entirely, or coat it thickly with tar. Rubber suction hoses are often offenders in this respect: in tropical countries the rubber deteriorates and becomes porous to a certain degree.

The strength of the springs on a valve of any particular size should be proportioned to the lift and the speed of the pump; excessive shock at the end of each stroke indicates weak springs, or too great a valve lift.

The water piston should be a parallel, not a coned fit, on the rod, and the nut securing it to the rod should not serve also to hold the follower ring, though this may be contrary to usual practice. This packing will, in any case, require frequent renewal, and in tightening up the main nut there is nothing to prevent the rod from going round. Accordingly, the exposed part of the rod between the cylinders is gripped with the nearest pipe tongs, and that is the beginning of the end of the pump.

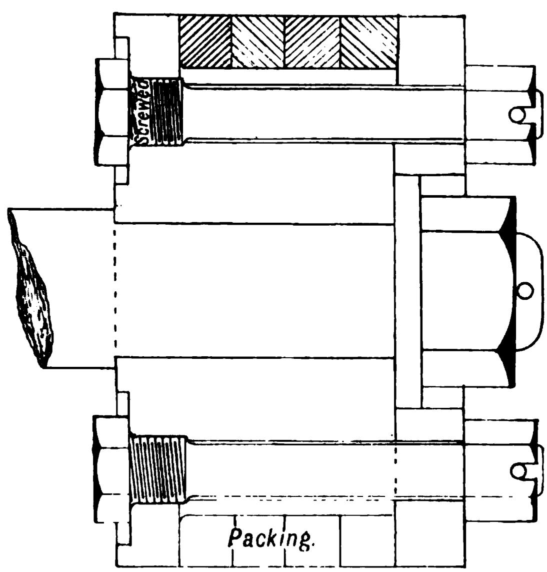


FIG. 42.—Packed Water Piston.

Fig. 42 shows a packed piston with ring held independently of the main rod nut.

If the follower ring is removed and the pump allowed to work a few strokes, the old packing will be thrown out. The new material should be cut into lengths making snugly fitting rings when pressed into the pump barrel. Many square rubber-cored packings are made for the purpose, plaited hemp gasket will do, but few stand so long as the Garlock packing, made in Chicago.

When cup leathers are used, either a constant supply must be arranged for, or a quantity ordered at a time; as neither of these plans is free from defects, they are often made at the mine. The moulds, of which there should be at least a pair to every pump, may be made of any tough hard wood. Fig. 43 shows metal moulds, the dotted lines indicating the position when tightened up. The mould x should be bored slightly taper, about $\frac{1}{16}$ in a depth of $1\frac{1}{2}$ in., the diameter at half the depth of the ring

being equal to the bore of the pump, the upper edge well rounded off. The die A is turned to a diameter corresponding with the smallest bore of the mould X, less twice the thickness of the leather to be used. Lower edge to be well rounded off, as shown.

In making cup leathers, the material, which should be of best quality and even thickness, is first cut into circular pieces slightly exceeding the bore of the pump, plus twice the depth of the cup when finished. Each piece of leather is now thoroughly soaked and worked in hot water, and while still hot and wet, a mixture of oil and tallow is rubbed on and allowed to soak in for a day or two. Before being placed in the mould, the leather should again be softened with warm water. Lubricate the mould with beeswax, tallow, or soap, and after screwing up, allow the mould to remain a few days in a warm dry place. When the leather has

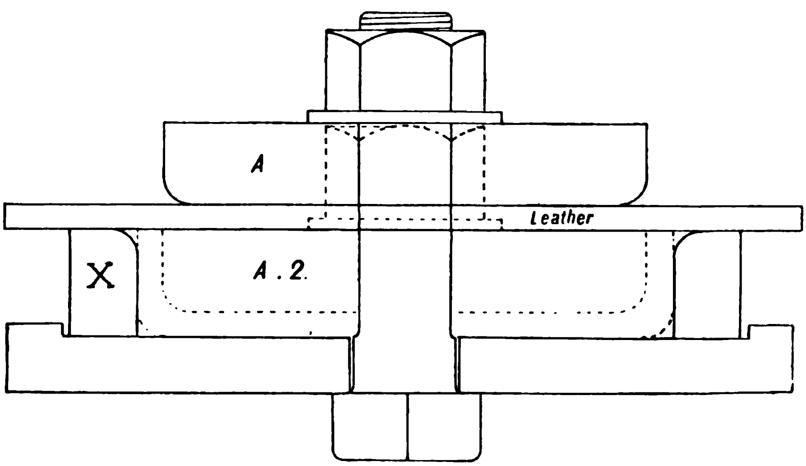


FIG. 43.—Mould for Cup Leathers.

hardened, the upper edge is trimmed off level with the top of the mould, and after removal, the inner edge of the cup is bevelled outwards (see Fig. 44), and the bottom hole enlarged to fit the pump piston.

Leathers so made will outlast most imported ones. The complete piston is shown in Fig. 44; it is of the utmost importance that the centre ring B is well hollowed out to support the back of the cup leather.

Adjustment—Steam End.—If the joints at the water end are tight, the valves, pistons, and plungers free from leakage, the trouble probably lies at the steam end; though the pump may refuse to move if the suction pipe is choked, or the strainer buried in mud.

At the steam end the reversing mechanism is usually the weak point. In the Tangye, flats are worn on the ends of the tappet valves, where they

project into the cylinder and are rubbed by the piston. These ends should be rounded up with a file and slightly hardened. When replacing the valve, grind it in, to make sure it is steam tight. When on their seats the points should project about $\frac{1}{8}$ of an inch into the cylinder bore. It may be the stems are too short and the lift insufficient; in this case new valves are necessary, though a careful smith can often lengthen the three-cornered part of the spill and give the valve a new life.

Piston valves cannot be tightened, as they are not fitted with spring rings; but then the wear is very light, almost inappreciable in fact, and they last as long as the other parts. In case of accident, a new valve chest and valve can be obtained, as all respectable pumps are made to gauge and template.

Owing to irregular lubrication, wet steam, and standing idle at times, flat valve faces are subject to considerable deterioration, and require refacing pretty frequently, once a year at least. The valve's condition may be tested by placing it at half stroke and seeing if steam issues through the cylinder drain cocks.

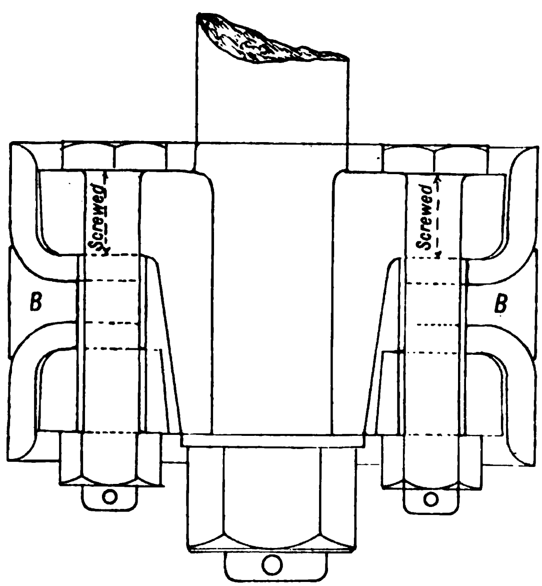


FIG. 44.—Pump Piston with Cup Leathers.

To set the slide valves of Duplex pumps, both pistons should be placed at the centre of their strokes, indicated approximately by the position of the valve levers; and the slide valves are adjusted on their spills until they overlap the steam ports equally at each end. A certain amount of play is often intentionally allowed between the valve and its spindle, and if this is taken up, the working stroke of the pump is shortened.

The tightness of the piston may be tested by admitting steam on one side and opening a drain cock on the other. When fitting new rings, it is well to remember many pumps have separate ports for steam and exhaust. The piston rings have to travel across the exhaust ports, and in placing them in the piston, care must be taken their open ends are not in line with these ports, or a plentiful crop of broken rings may result.

Tailings Pumps.—Although pumps may be used for the purpose of raising tailings, the process cannot be considered an economical one, unless the battery water is also required at a higher elevation. To be successfully dealt with in this way, the tailings must be in a state of very thin pulp, and the quantity of water pumped is necessarily large in proportion to the tailings raised.

These pumps, as a rule, deal with the pulp as it leaves the amalgamating tables ; the tailings being raised for re-treatment, and the water to be again used in the battery. The plunger type is always preferred, and they are usually arranged in pairs, so that the constant delivery prevents sand from settling in the valve boxes and passages. Jets of clean water, admitted beneath the stuffing-box, prevent the sand from embedding itself in the packing and scoring the plungers. The valves have narrow beats and work on risers. Hinged valves are troublesome, as the sand accumulates under the hinge and prevents the valve from closing fairly on its seat.

Centrifugal Pumps.—These are largely used in cyanide and battery work. The water is lifted by the centrifugal action of revolving vanes and no valves are required, though a foot valve is often placed at the end of the suction pipe. In some patterns the suction and delivery branches stand at a fixed angle, while in others they can be turned round on the pump casing to the angle required. In the same way the suction is sometimes balanced, the supply being drawn in on each side of the casing; the object of this arrangement being to avoid the end thrust caused when the suction is on one side only. The speed of the water in the pipes is from 5 to 7 ft. a second, and the pump vanes revolve at a high speed, the actual speed depending on the height of the lift and the quantity of water to be raised.

In a pump of any given efficiency, the work done is in direct proportion to the driving power, and the same pump at the same speed will deliver a large quantity of water at a low lift, or a smaller quantity at a higher lift. The maximum lift is about 50 ft., it does not usually exceed 25 or 30 ft. ; but by connecting several of these pumps in series, the discharge of the first becoming the suction of the second, and so on, lifts up to 1,000 feet can be arranged for. When clean water is pumped, the wear is very slight, but gritty water from settling pits soon increases the clearance of the vanes, and the efficiency falls off. For this class of work the pump body can be fitted with renewable liners.

CENTRIFUGAL PUMPS.

Diameter of pipes, in inches	3	4	5	6	7	8
Diameter of pulley, in inches	4	5	6	7	8	9
Weight, in cwt.	2¾	3	3½	5	7	7½
Gallons, per minute	90	160	280	400	550	750
H.P., per foot of lift	0.05	0.09	0.16	0.22	0.31	0.42

Donkey Pumps.—Even when the feed is supplied by a pump driven by the main engine, a donkey is required in reserve, for use in emergency and when the engine is idle. The ram type is preferred for this purpose, and for pressures up to 100 lbs. per square inch, the vertical pattern, with inverted cylinder, crank and flywheel, is generally used. The following table gives the sizes and capacities of Cameron pumps of this type:—

CAMERON PUMPS, WITH SINGLE CYLINDER AND SINGLE-ACTING RAM.

Diameter of cylinder, in inches	5	5	6	7	7	7	8½
Diameter of ram, in inches	3	3½	3½	4	4½	5	6
Stroke, in inches	5	5	5	6	6	6	8
Gallons per hour, approximate	670	900	900	1,250	1,600	2,000	3,200

CAMERON PUMP, WITH TWO CYLINDERS AND TWO SINGLE-ACTING RAMS.

Diameter of cylinder, inches	5	5	7	7	7	8½	9	12
Diameter of rams, in inches	3	3½	4	4½	5	6	7	8
Stroke, in inches	5	5	6	6	6	8	8	9
Gals. per hour, approximate	1,300	1,800	2,500	3,200	4,000	6,400	8,800	11,500

For high steam pressures and large installations, the direct-acting pump is preferred; having neither crank nor dead centre, it possesses a wider range of speed than the rotating pattern, and can be run at the lowest rate without danger of stopping. Another advantage, due to the non-rotating action, is that a good length of stroke may be secured within moderate over-all dimensions. The table on page 119, and Fig. 45, refer to the Evans' "beam" pump, a direct-acting type in which the steam cylinders are compounded, and suction and delivery branches provided on each side of the water end. The capacities given are based on fifty single strokes of each ram per minute:—

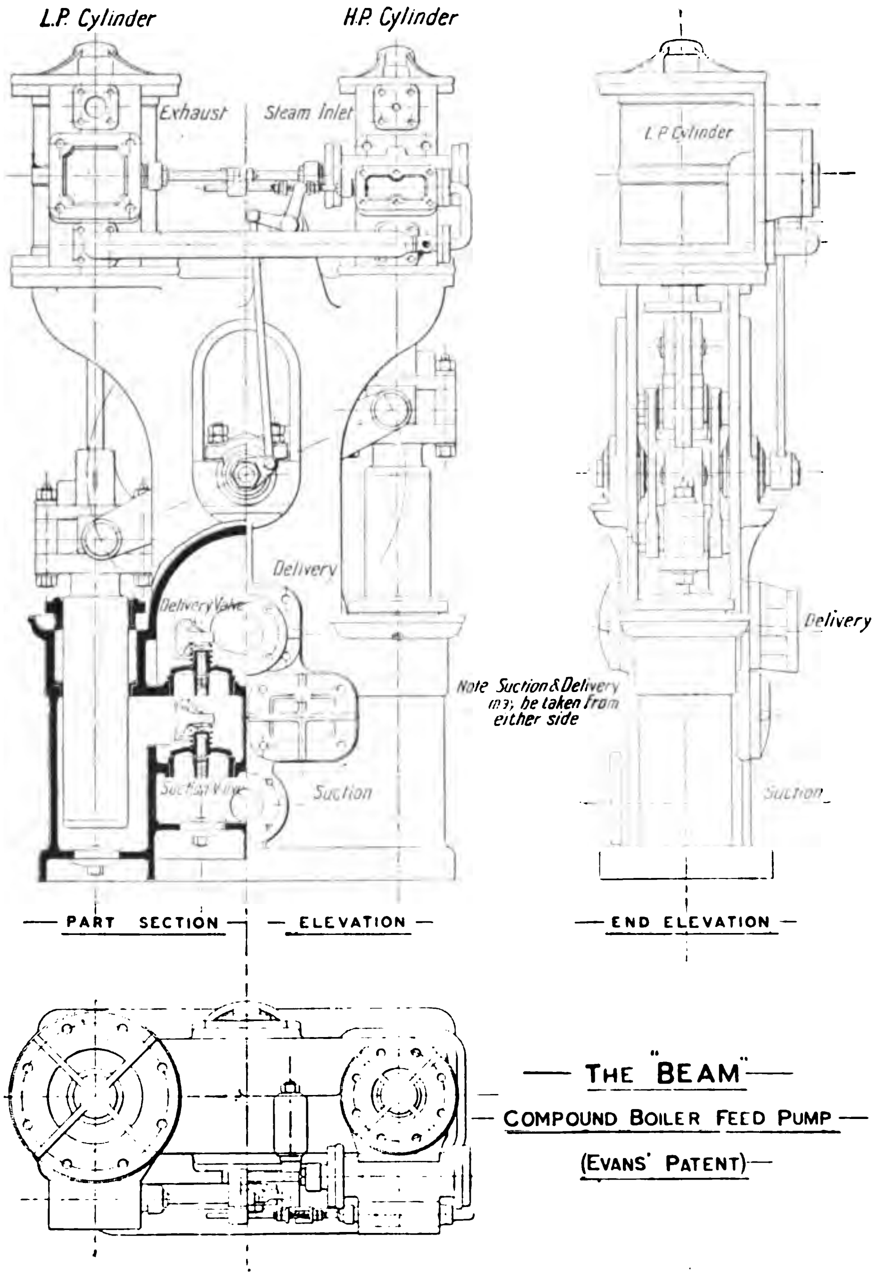


FIG. 45.—Evans's "Beam" Compound Feed Pump.

Diameter of high-pressure cylinder, in inches	4	5	6	7	8	9	10
Diameter of low-pressure cylinder, in inches	7	9	10	12	14	16	18
Diameter of rams, in inches	3½	4½	5½	6½	7½	8½	9½
Suction and delivery, in inches	2	2½	3	3½	4	5	6
Steam inlet, in inches	½	½	¾	¾	1	1	1¼
Exhaust, in inches	1½	1½	2	2	2½	2½	3
Gallons per hour	930	1,540	3,080	4,300	5,730	7,360	9,180

Steam Pumps—General.—It cannot be too clearly understood that the pump should, in every case, be of ample capacity for the work required. A small pump, racked to its utmost limit, is more than usually wasteful in steam, is constantly giving out, and before its short life is over, has been an utter nuisance to all who have had to deal with it.

How different the slow powerful stroke of the pump working well within its capacity; the water passes quietly through its passages, noise and wear are reduced to a minimum, it lasts longer, works more economically, and as the Cornish miner said, "goes on pumping and says nothing to nobody."

No matter how small the pump (in fact, the smaller, the more necessary it becomes), let it be raised to a convenient and accessible height above the ground or floor level.

Let the patterns and sizes in use throughout the mine be, as far as possible, identical; time is wasted when connections require alteration each time a pump is changed, and when such work is taken in hand, no one is quite sure when it will be finished. If this plan is adopted, a spare pump may be kept, either under repair or ready for work in either of several situations.

The machine tools with which each mine is equipped enable such thorough overhauling and repair to be made, that, as far as working surfaces are concerned, the pump is again new.

The piston rods and rams can be turned up, new bushings and glands being provided to suit their slightly decreased diameters, all steam and water valves and their seatings refaced, and wear taken up in the joints and connections of the valve motion.

CHAPTER VIII.

WINDING MACHINERY.

Winding Engines, Arrangement—Portable Types for Underground Use—Combined Pumping and Winding Engines—Geared Engines—Setting Foundations—Direct-acting Engines—Ropes—Shackles—Splicing—Kibbles—Cages—Skips—Headgears—Table of Inclines.

STEAM, electricity, compressed air and water, furnish the motive power for hoisting purposes; it is scarcely necessary to include the windlasses and horse-whims used in the early days of the prospecting stage. In all cases economy in motive power is of secondary importance, and complex gear out of place in engines intended for this purpose; the requirements approach those of locomotive practice, reliability and handiness being the essential features. It is, therefore, only in special engines designed for deep winding that expansion gear is provided, cylinders compounded, or condensers added.

The general requirements have been embodied in patterns which may be considered standardised, and a dozen engines of the same design will work equally well, and be equally suitable for their work, in a dozen different parts of the world.

The engine must, in every case, be sufficiently powerful to thoroughly control the load attached to it, and must itself be completely under control of the driver; such conditions may be fulfilled, and yet permit considerable variation in detail and even in general arrangement. Should the engine be intended for underground work, compactness is essential; but space is cheap at surface, and nothing is gained by crowding the working parts together. For instance, when the drums are placed in front of, instead of over, the cylinders, the valve gear is more accessible, the driver's view less obstructed, and there is less danger of loose coils of rope becoming entangled in the gearing; even in underground engines, when space can be spared, the arrangement permits a greatly increased radius in which the rope may leave the drum.

The motive power required is in proportion to the gross load and hoisting speed, the gross load being the weight of the unbalanced part of the rope and everything attached to the rope. The speed is evidently a factor as the weight in pounds multiplied by the feet it is raised per minute is the

useful work performed by the motor, expressed in foot-pounds. It may be noted that the depth of the shaft is not taken into consideration; but for the few additional hundredweights of unbalanced rope, no more power is required to raise a given load 100 ft. at any depth in the shaft. As the shaft increases in depth a larger hoist is installed, not because the old one was not powerful enough to lift the load, but because it could not do so at the greater speed necessitated by the increased depth.

Practically all winding engines are furnished with two cylinders with cranks at right angles to each other, so that they may start readily from any position; the controlling levers should be not only within reach, but within easy reach of the driver. In a colliery engine a driver need not rise from his chair, and on metalliferous mines a man with such responsible duties might receive more consideration in the arrangement of these details. He should be able to reach the handles without stooping, or stretching his arms above his head; in foot-operated brakes the pedals should be placed where his feet would naturally be when standing at the handles. The driver's position is an important element in his day's work; as a rule he is not an acrobat, and possesses only the average number of hands.

Only on exceptionally deep mines are the drums mounted directly on the crank shaft; as a rule they are driven by gearing and make about one revolution to four of the engine; their dimensions should be sufficient to carry the required length of rope without any overlapping of the coils. In small engines they are mounted on side frames above the cylinders, an arrangement saving some space but open to objections already alluded to. By connecting one rope to its upper, and the other to its lower surface, one drum may be made to command two winding compartments; this arrangement answers very well when most of the hoisting is from one level, but necessitates disconnecting one cage each time an alteration in depth is made. When hoisting from only one compartment, a saving will be effected in the wear of the engine if the drum can be disconnected by a clutch and lowered by the brake. In double drum engines fitted with clutch gear, the balancing effect of the descending load need not be sacrificed, while alternate loads may be taken from different depths, or each drum used independently when required.

Separate brakes are fitted to each drum and consist of a wrought-iron strap lined with wood, or posts on opposite sides of the drum; band brakes should be suspended by a spring or balance arrangement, so that they do not hang on the rim. Brakes are always operated by a pedal action, leaving the driver's hands free for the steam and reversing levers.

The indicator should be positively driven by worm or tooth gear, and its divisions plainly visible from the driver's place; as an additional safeguard, it is advisable to give the driver a clear view of the shaft brace.

The smallest winding engines found on a gold-mine are the air-driven winches used for temporary purposes underground; they are of great assistance in winze sinking, enabling the debris to be cleared and work quickly resumed after blasting. In all wet winzes the water seriously retards the rate of sinking, being sometimes more than the hand windlass can deal with, and in any case adding considerably to the labour required. When

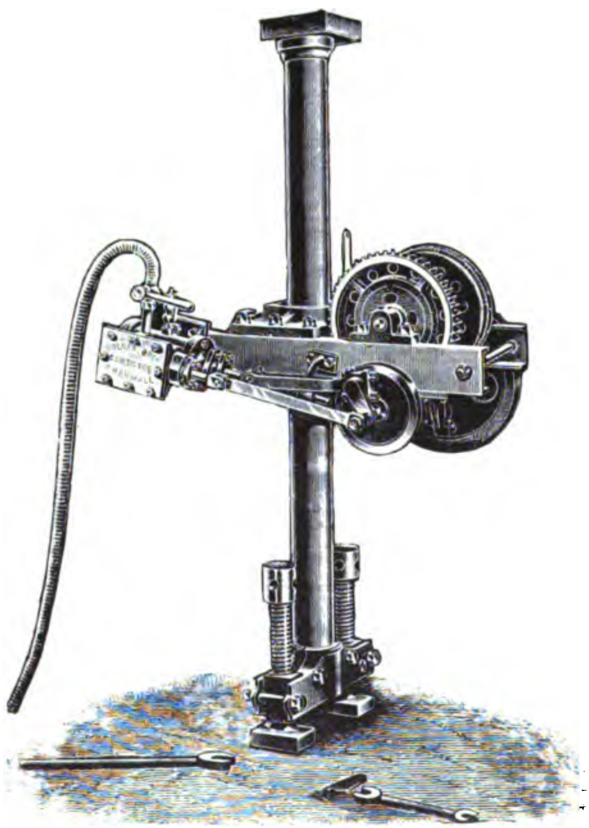


FIG. 46.—Holman's Patent Portable Underground Hoist.

the question of installing an air winch arises, it is often urged that, by the time the chamber is cut and bearers fixed, the sinking will be completed.

This difficulty is overcome in the portable hoist patented by Messrs Holman Brothers, Camborne, and illustrated in Fig. 46, in which foundations, in the usual sense of the word, are entirely dispensed with. The complete machine can be taken anywhere in an ordinary mine truck, and is simply

clamped to a common rock drill column, requiring no further support. It can be placed wherever a rock drill can be fixed, works equally well in any position, and if fitted immediately over the winze, the rope may lead from the drum direct to the bucket, without passing over any intermediate pulley. The idea is such a happy inspiration, and so completely fills. all temporary requirements, that one can only wonder why it was not thought of before.

The same makers also have a line of double-cylinder winches, mounted on box-beds and steel A frames, suitable for underground work or the earlier stages of shaft sinking ; a pumping crank can be added if required. Particulars are given below.

HOLMAN PROSPECTING HOISTING ENGINES.

Cylinder Dimensions.	Drum Dimensions.	Approximate Weight.	Size of Bedplate.
4 in. × $5\frac{1}{4}$ in.	8 in. × 12 in.	9 cwt.	1 ft. 11 in. × 1 ft. 7 in.
5 ,, × 7 ,,	12 ,, × 16 ,,	20 ,,	2 ,, 2 ,, × 2 ,, 2 ,,
6 ,, × 8 ,,	15 ,, × 20 ,,	25 ,,	3 ,, 6 ,, × 2 ,, 6 ,,
8 ,, × 10 ,,	30 ,, × 30 ,,	70 ,,	6 ,, 0 ,, × 3 ,, 6 ,,

A steam hoist with a pair of cylinders, each 6 in. diameter by 10 in. stroke, is the smallest size erected at surface ; the cylinders are horizontal, in some cases inclined upwards. Wrought-iron framing is generally used, as saving weight in transport, but is seldom sufficiently rigid for any but the horizontal patterns. A considerable output is possible with these small hoists, with a working load of only 10 cwt. ; in the early days of the Mysore Mine monthly returns of 2,000 ounces of gold were made, all the quartz being hoisted by an engine of this size, steamed by a small vertical boiler.

Fig. 47 shows an exceptionally useful arrangement, suitable for both hoisting and hauling, on account of the large arc in which the rope may leave the drum. This is a feature of some importance, as when the depth exceeds 300 ft. and the winding speed becomes too slow, such engines have a further career of usefulness in the mine or at incline haulage. The handles are brought well together, and the drums may be of wrought iron when transport is a consideration.

The following table gives an idea of the sizes of winding engines in general use, and their working loads when lifting at 500 ft. a minute ; this does not mean starting the load at a depth of 500 ft. and delivering it at surface in a minute, allowance must be made for time occupied in accelerating at starting, and slowing up at surface.

WINDING ENGINES.

Dimensions of Cylinders, in inches	8 × 12	9 × 16	10 × 18	12 × 18	14 × 20
Drum, in feet	5 × 1½	5 × 1½	6 × 1½	6 × 2	7½ × 2
Working Load, in cwt. . . .	15	20	25	35	55

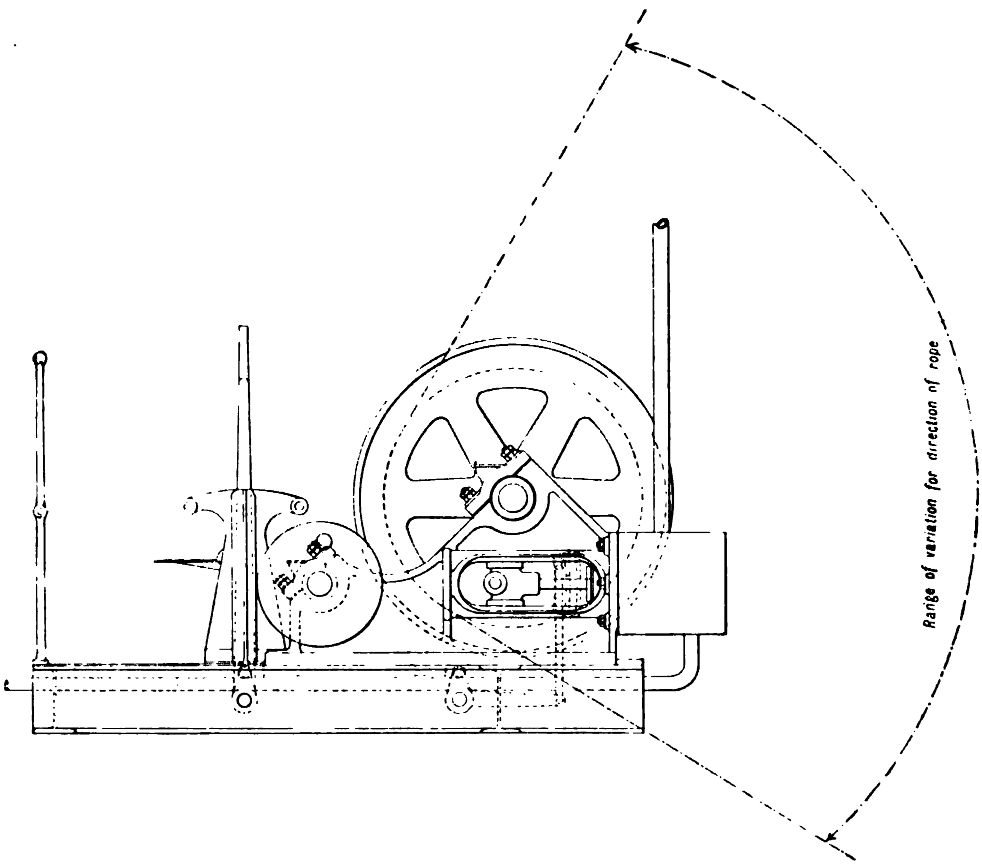


FIG. 47.—6-in. by 10-in. Hoist, for Winding and Hauling.

In preliminary work, pumping and winding are sometimes performed by the same motor; such an arrangement can only be of temporary use, and the gear should not be permanently attached to the engine, but driven by clutches, so that each operation may be independent of the other. This method of connection permits the engine to be subsequently used for other purposes without serious alteration.

In the following table the combinations allow a winding speed of 500 ft.

a minute, the pumps not being more than 7 in. in diameter, and the stroke not exceeding 4 ft.

COMBINED PUMPING AND WINDING ENGINES.

Dimensions of Cylinders, in inches	9 × 12	10 × 14	12 × 16
Drum, in feet	5½ × 1½	6½ × 1½	7 × 2
Load, in cwt.	20	27	35
Depth Pumped, in feet	400	525	800

The winding engine occupies no definite position with regard to a vertical shaft, and any convenient site may be chosen; usually the headgear is squared with the shaft, the sheaves and bearers with the headgear, and the engine consequently stands so that its drum axis is parallel with the side of the shaft. There is less choice in the case of an incline shaft, as the engine cannot stand at either end, and must be placed in front or behind; if behind, the angle the rope makes in passing over the sheave is doubled; this position, therefore, is not selected if the alternative is feasible. In hilly country it may be that the back of the shaft is the only place open for the engine; if so, the only difference is a little increased wear on the rope; skips can be arranged to self dump from either direction.

In laying off the foundations, it is best to sight down an incline shaft, and peg out at surface a line in the same vertical plane as the centre of the winding compartment; this fixes the drum centre, and a line squared with it will be the drum axis. With vertical shafts, the line may be projected in any direction from the winding centre, as already explained, but the axis of the drums must be square with this line, or the rope will always crowd to one end of the drum.

The distance from the shaft to the engine depends on several factors, the height of the headgear being one, the position of steam supply another. Naturally, the site chosen will be near the steam supply, and afford the driver a clear view of the brace; if too far from the shaft, guide pulleys will be required to steady the rope against vibration caused by irregular torque of the motor. On the other hand, if the engine is too close to the shaft, there will be unnecessary friction between the rope being wound on the drum, and the coils already wound. As a general rule, it is safe to let the distance between the nearest side of the shaft and the nearest end of the foundation pit be equal to the height of the headgear.

As the load is light, the foundations are less massive than for pumping machinery, and the smaller hoists may be bolted down to well-bedded mud cills; while in the semi-portable type, the box-bed, let a foot or two into the ground, is all the foundation required.

Figs. 48 and 49 are plan and elevation of 12-in. by 18-in. winding

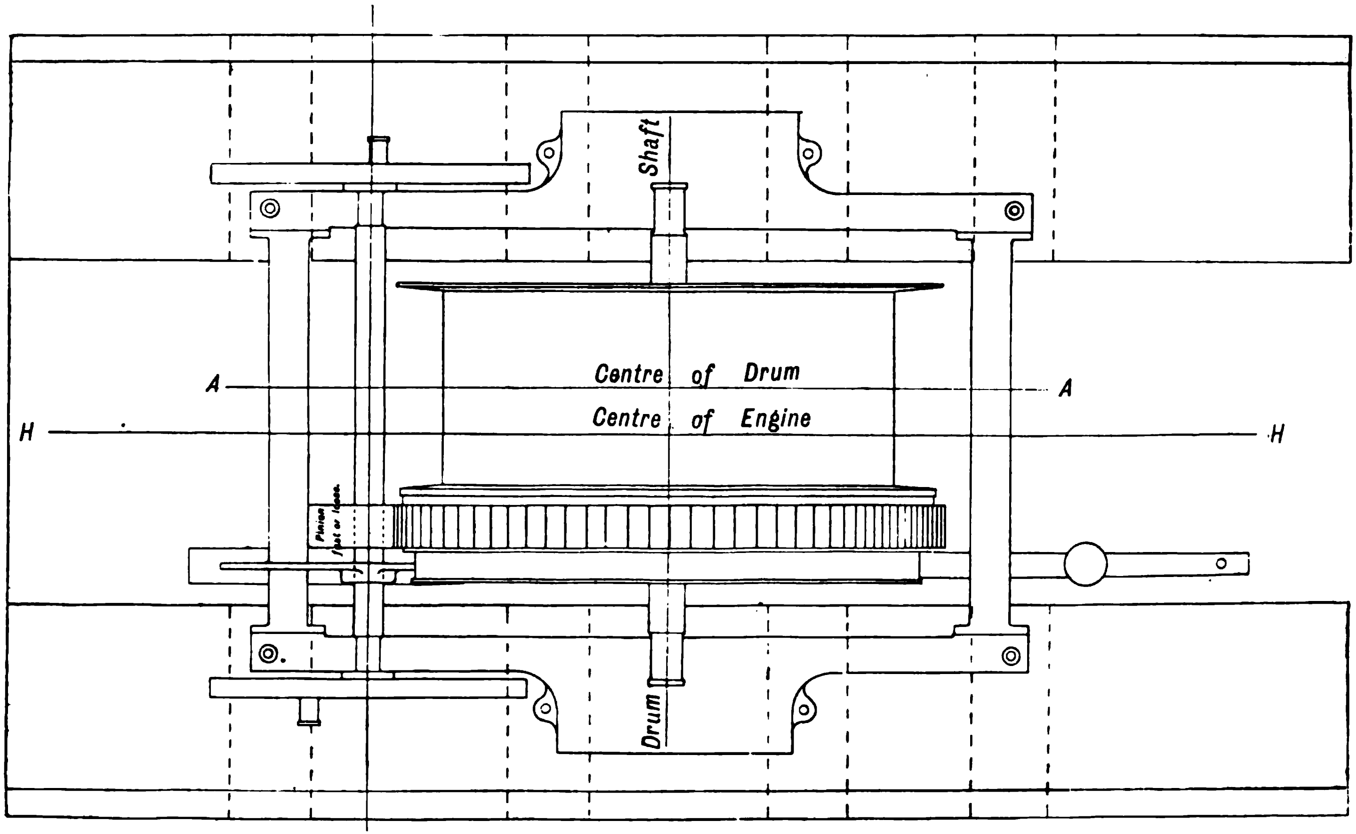


FIG. 48.—Plan of 12-in. by 18-in. Winding Engines.

engines, of a type largely used on the Indian mines, until their depths exceeded 1,200 ft. In Fig. 48 (in which the brake band is removed),

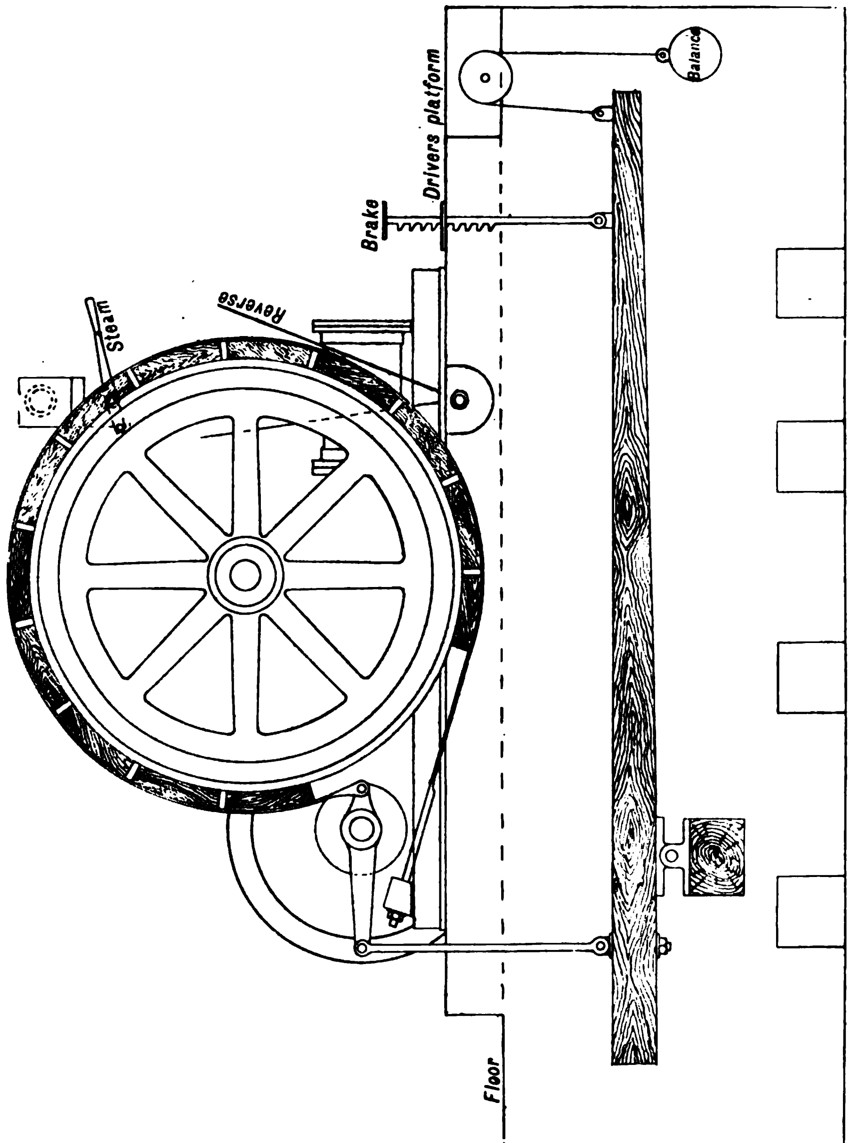


FIG. 49.—Elevation of 12-in. by 18-in. Winding Engines.

the line A A is the centre of the drum, and is the one originally laid off from the shaft; the engine centre H H does not coincide with it.

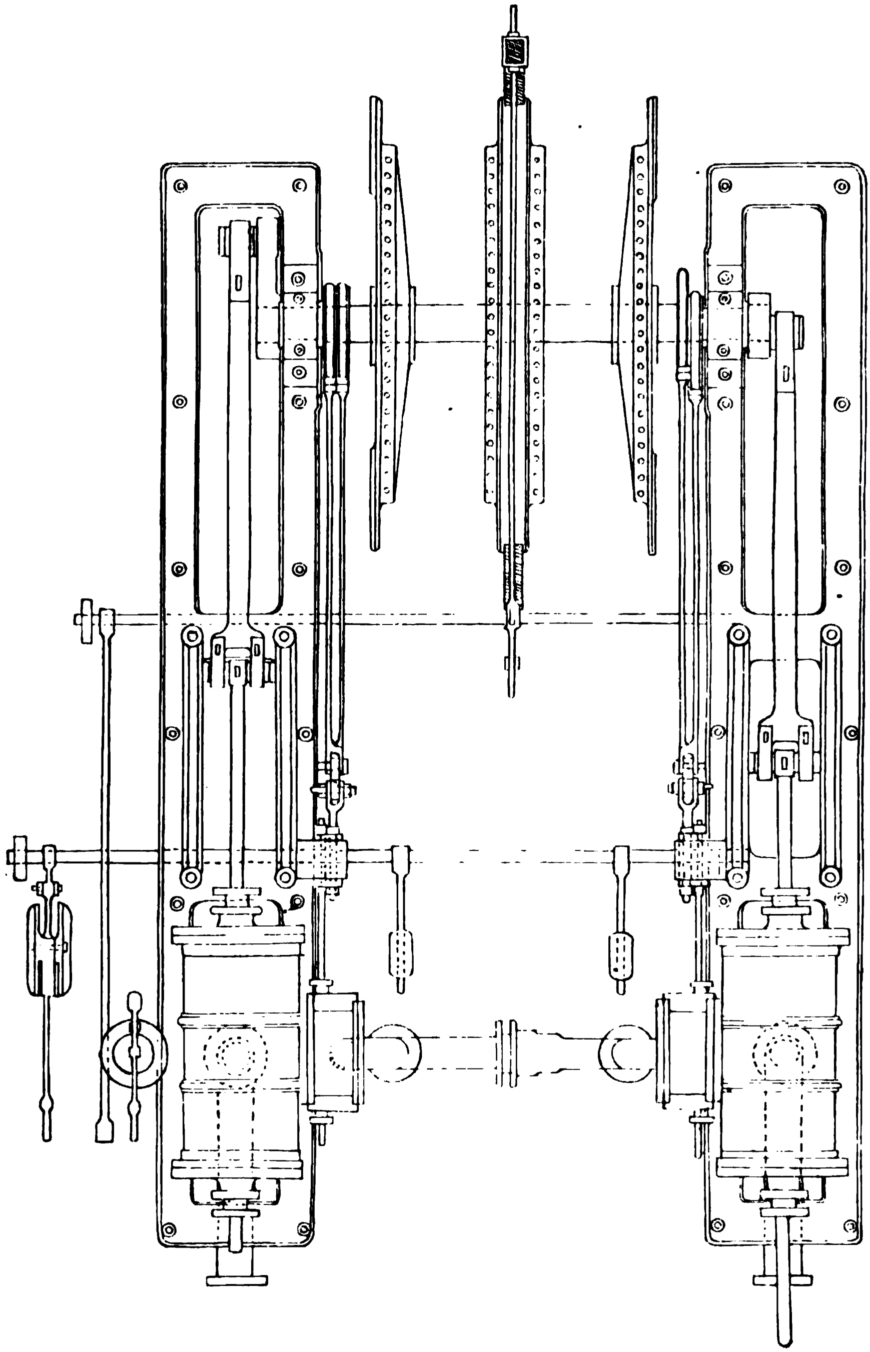


FIG. 50.—Plan of Direct Winding Engine, with Double Drums and Post Brakes.

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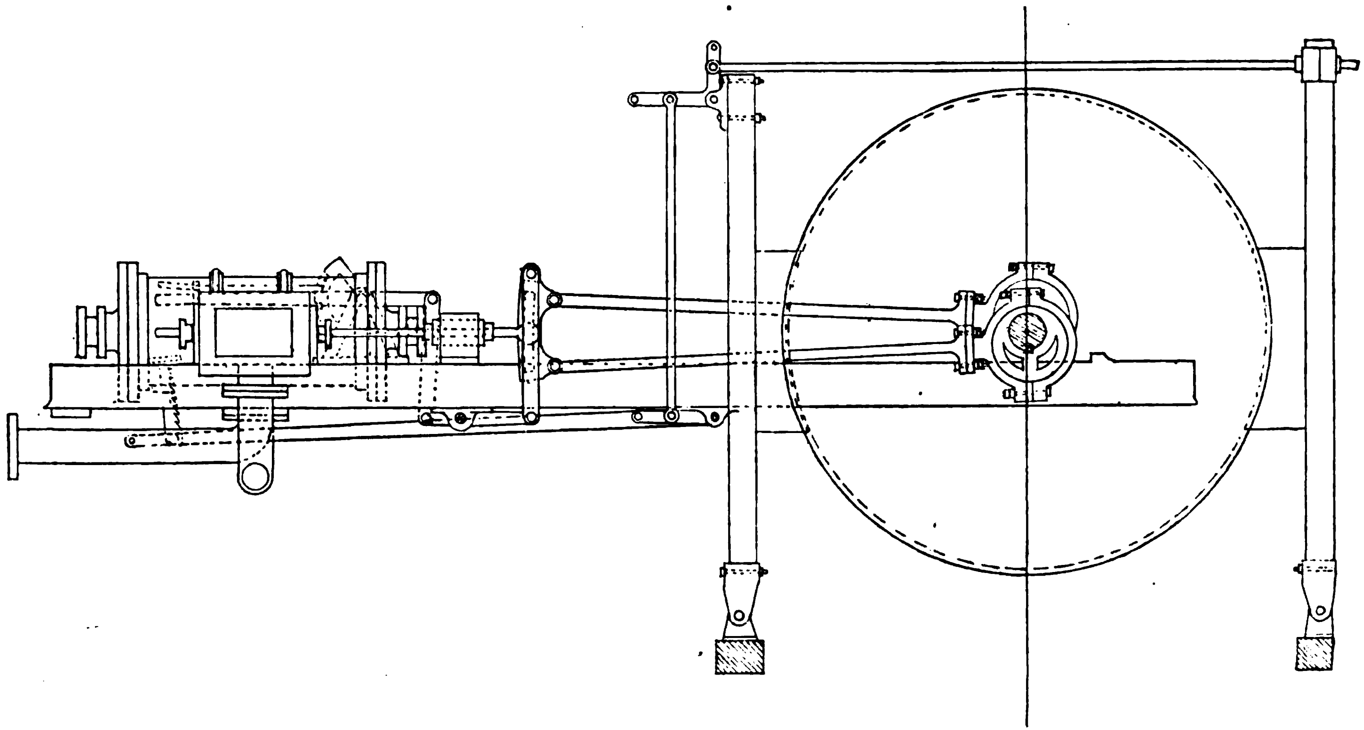


FIG. 51.—Elevation of Direct Winding Engine shown in Fig. 50.

It is from this latter line H H that the masonry piers forming the foundation are laid off. The line representing the centre of the drum axis is carefully squared, and from it the positions of the crow holes are located by measurement. The cross bearer carrying the brake staff is built into the loading as the work proceeds, and at the top recesses are left for the crank discs and reversing arbor. The drums are lagged with wood and mounted on upward extensions of the engine framing, the indicator being driven by worm gear from the end of the drum shaft.

The annular spur wheel, bolted to the side of the drum, is driven in three different ways—(1) The pinion is permanently keyed to the crank shaft; (2) loose pinion driven by dog clutch; (3) pinion mounted on sliding keys and thrown into or out of gear with the drum. The first plan does not permit the disconnection of the drum, and the engine must be at work both in hoisting and lowering; either of the other plans permits the cage to be lowered under the brake, and the third plan can be recommended for all moderate requirements. In this case the pinion may be meshed whenever its teeth are opposite the spaces of the spur wheel, and the opportunity for engagement occurs more frequently than is possible with any form of dog clutch.

Many American hoisting engines are fitted with a neat clutch gear worked by a quick thread screw spindle passing through the drum shaft.

The engines hitherto considered are of sufficient capacity for ordinary purposes, but may not permit the output required should the depth exceed 2,000 ft. It is then considered preferable to increase the speed of winding rather than the weight of the load; accordingly gearing is dispensed with, and the drums mounted on the crank shaft, as in colliery practice. The following examples give an idea of the speeds, loads, and outputs of these directly connected engines, as illustrated in Figs. 50 and 51, which also serve to show the arrangement of post brakes.

An engine with a pair of cylinders 24 in. diameter by 48-in. stroke, coupled to drums 11½ ft. in diameter, and raising a net load of 1¼ ton at a speed of 2,000 ft. a minute, will be capable of an output of 12,000 to 15,000 tons a month from a depth of 2,000 ft.

On the deep level mines of South Africa, engines with cylinders 20 in. diameter by 48-in. stroke, coupled to 8-ft. drums, lift a gross load of 2½ tons at 1,800 ft. a minute.

At the Lake Superior copper mines a pair of compound condensing Corliss engines, with cylinders 16 in. and 32 in. diameter by 48-in. stroke, coupled to 7-ft. drums, raise a gross load of 2 tons at a speed of 1,200 ft. a minute.

Perhaps the greatest output in a given time must be credited to De Beers Mine, where a pair of vertical engines with 9-ft. drums, coupled to self-dumping skips weighing 7 (short) tons when filled, have hoisted over 3,500 tons per shift from a depth of 1,200 ft.

Motive powers other than steam are not in sufficient general use to warrant detailed description; an illustration of an electrically-driven winding engine is given in Fig. 7; though electricity is better suited to work, requiring less stopping and starting. In using water power, a wheel of the impact type is preferred to the turbine, one wheel being coupled to each drum; the power supply is governed by a lever actuating a pointed rod, which closes the nozzle and shuts off the supply.

Ropes.

For winding work the round wire rope has practically displaced all other forms. The qualities of steel principally used in its manufacture are plough, crucible, and mild; there are in addition several intermediate and fancy brands. Each rope consists of six hemp-cored strands wound around a central hemp core, these cores making a lighter and more flexible rope than wire ones. While the number of strands remains constant, the gauge of wire varies considerably, being largest in ropes having few bending strains to bear, such as guides and stays; where flexibility is essential, the finer gauges of wire are used. The rope used for winding purposes is a compromise between these extremes.

If a piece of iron is bent when cold, the tensile strain on its outer surface is apparent to the eye; the same strain occurs in a modified degree each time a wire rope passes round a pulley. The crown of each top strand is strained according to the radius of the circle in which it is bent; the greater the circle, the less the strain; under equal conditions this strain would be more severely felt in larger ropes, as their opposite sides are farther apart. A relation therefore exists between the thickness of the rope and the diameter of the pulleys and drums it works over; an easily remembered rule is, 1 ft. of pulley for each $\frac{1}{8}$ in. of rope, that is, an 8-ft. pulley for a 1-in. rope.

In ordinary ropes the wires of each strand are twisted in the opposite direction to the strands themselves; in Lang's lay this is reversed, and as the result of twisting the wires with the lay of the rope, there is less tendency to twist in working, and a long-wearing surface is secured on the crown of each wire.

Round Wire Ropes.

Diameter.	Weight per Fathom.	Plough Steel. B.S.	Plough Steel. Working Load. Fast.	Plough Steel. Working Load. Mod.	Crucible Steel. B.S.	Crucible Steel. Working Load. Fast.	Crucible Steel. Working Load. Mod.	Mild Steel. B.S.	Mild Steel. Working Load. Fast.	Mild Steel. Working Load. Mod.
Inches.	Lbs.	Tons.	Cwt.	Cwt.	Tons.	Cwt.	Cwt.	Tons.	Cwt.	Cwt.
½	2¼	10½	21	26	8	15	19	4	8	10
⅝	3½	17	35	44	13	26	32	7	14	17
¾	5	25	50	62	18	36	45	10	20	25
⅞	7	36	72	90	26	52	65	14	28	35
1	9¾	45	90	112	32	64	80	18	36	45
1⅛	11½	55	110	137	39	78	97	22	44	55
1¼	14¼	65	130	162	46	92	115	25	50	62
1½	19½	96	196	245	70	132	170	38	76	95
1⅝	23	120	246	300	87	174	217	49	98	122
1¾	26½	136	272	340	96	192	240	53	105	130
1⅞	31½	160	330	410	118	236	295	66	132	165
2	35	188	376	470	133	266	320	74	148	185

The above table gives particulars of the sizes and qualities of ropes chiefly used, the weight being in pounds per fathom, the breaking strain in tons, and the working load for vertical winding given in hundredweights for fast and moderate speeds. The smaller sizes of the flexible ropes, ¼, $\frac{5}{16}$, and ⅜ of an inch in thickness, have largely displaced hemp and manilla for windlass work, and are used on barrels of 6 and 8 in. diameter.

All wire ropes are uncoiled from the outside, and for this purpose it is absolutely necessary to mount them on a revolving drum or barrel. In lieu of anything better, a wheel or pulley lying on its flat on a piece of flat iron, with a crowbar driven through the bore, will answer the purpose. Not a single coil should be allowed to slip off without a turn of the wheel. The end to be fastened to the drum is passed through a hole in the lagging, to which an inclined groove should lead to prevent a quick bend in the rope. The end may be fastened by passing it twice around the drum shaft and clamping it to the standing part. With small ropes one turn may be taken around the shaft, a half hitch around the standing part, and the end seized with wire.

Occasional lubrication with grease free from acid is beneficial if the rope is exposed to wet. All working ropes require frequent examination, though a careful inspection once or twice a week is better than a perfunctory glance daily. Broken wires are easily detected as the ends stand out. The chief thing to note is the thickness of the wires on the crowns of the strands, and the state of the rope near the shackle. Fig. 52 gives an idea of wear. This Lang's lay rope, made by Messrs Bullivant & Co., Ltd.,

had an original breaking strength of 29 tons; when taken off after two years' constant work its breaking strain was still 27½ tons. The even wear on the crowns, due to the Lang's lay, is particularly noticeable.

The most severe wear is in those incline shafts and winzes not furnished with rollers. In such situations a seven-eighths rope may last less than three months.

A short rule for the breaking strain of ropes of medium quality is that the circumference in inches squared and multiplied by 2½ equals the breaking strain in tons. The working load will be one-tenth of the breaking strain for fast winding, and one-eighth for medium speeds.

The shaft end terminates in an eye which is often supplied with the rope. If not, the end may be passed round a deadeye and secured to the standing part by one or more clamps. An alternative plan is to use a long or short shackle, shown in Fig. 53.

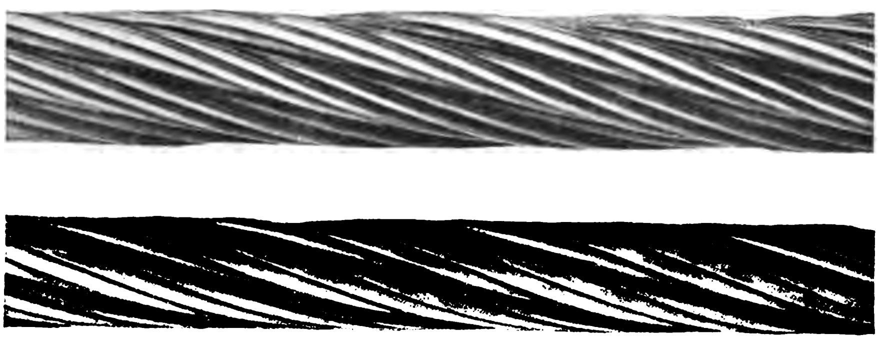


FIG. 52.—Lang's Lay Rope, before and after two years' use.

In this illustration the bow of the short socket is purposely enlarged for the sake of clearness. It is important that the upper edge of the taper socket be well rounded off, as shown.

After the socket is passed over the rope the latter is seized with copper wire, commencing about 2 in. from the end. The binding must gradually diminish in thickness, the number of layers depending on the gauge of wire used. The ends of the strands are then unravelled, the wires straightened, and each separately bent back over the copper binding. Extra taper may be given by cutting some of the wires shorter before bending them, and with some brands of steel the wires must be warmed before bending or they may crack. The socket is now dropped over the tapered end of the rope and an iron pin driven into the end of the hemp core.

In fixing a long socket the rope is bound as before, but for a greater length, a foot or more in this case. The shackle is sprung over the rope

and secured by tapered rings. These shackles are sometimes secured by rivets passing through the rope, but the plan cannot be recommended, as broken rivets escape detection. In every case a few feet of chain should intervene between the shackle and the load, or the end of the rope will suffer if there is any slack when the load is resting on the keeps.

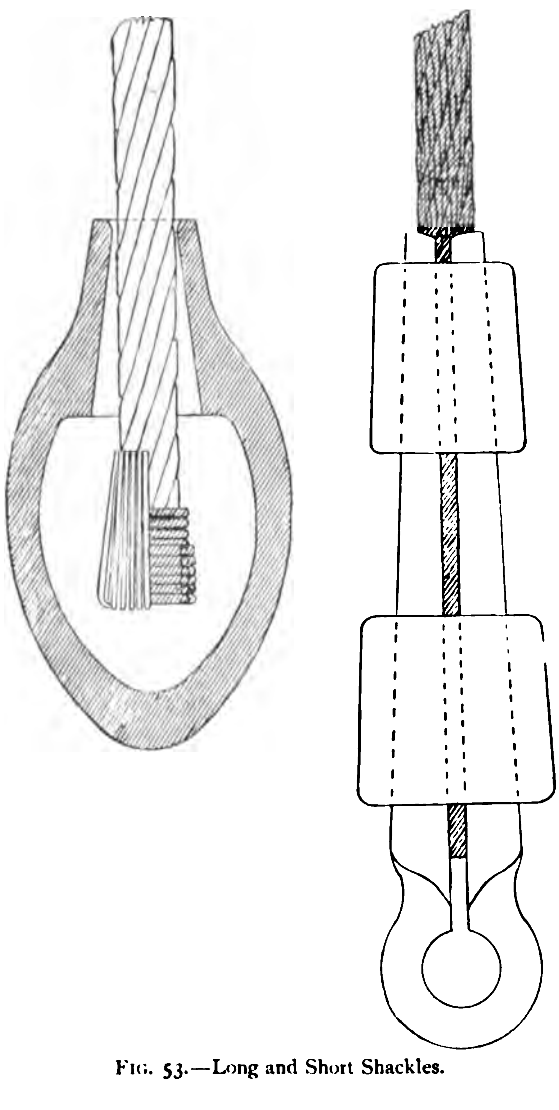


FIG. 53.—Long and Short Shackles.

Splicing.—When it is necessary to lengthen a rope, or remove a part nipped in the gear wheels, or otherwise damaged, the two ends may be united by short shackles; but if the part has to travel over pulleys, a splice is better and runs more smoothly.

A wire rope cannot be spliced with a pocket knife and a poker, proper appliances are necessary, and although neatness only comes with practice, any mechanic can make a strong and serviceable joint by following these instructions:—

1. The two ropes should lie evenly, side by side, supported on trestles or blocking, their ends overlapping from 30 to 40 ft., according to the size of the rope.

2. Midway between the two overlapping ends, serve each rope with a temporary binding, and unravel the strands of each rope as far as this bind-

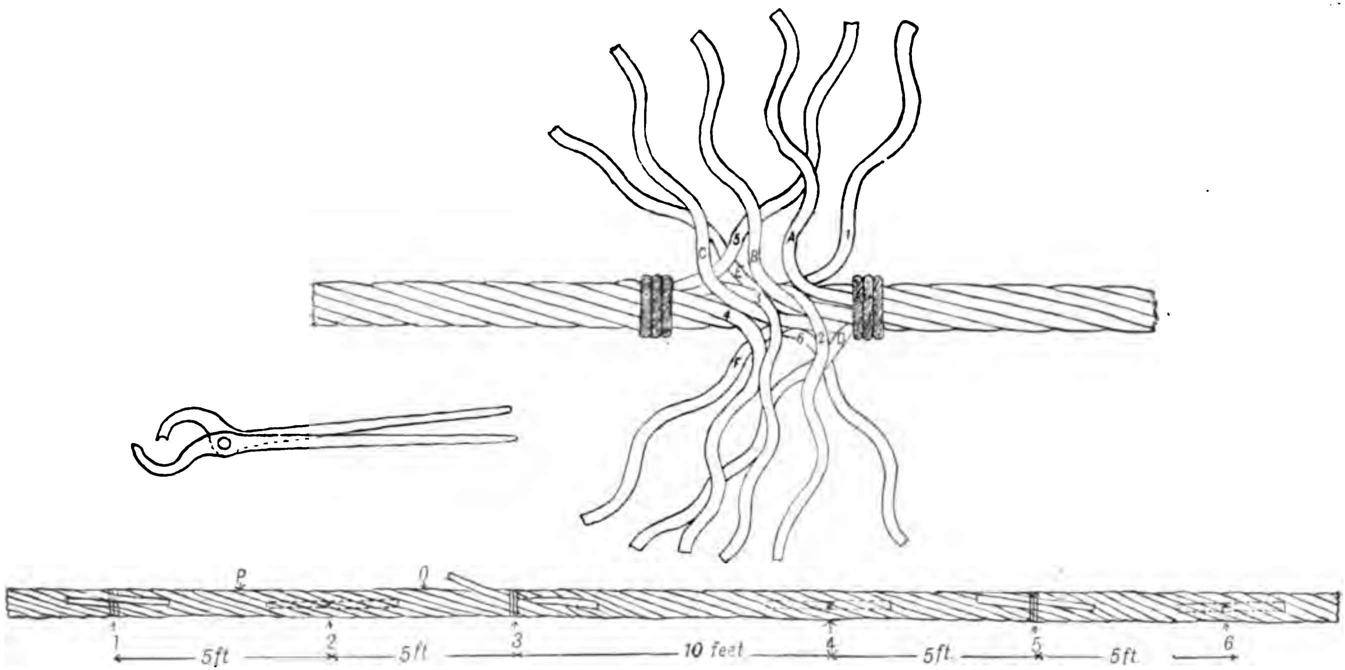


FIG. 54.—Splicing Wire Rope.

ing, having previously served the end of each strand. There will now be twelve loose strands, each 15 to 20 ft. long.

3. Cut off the loose hemp core of each rope close to the binding, bring the two ropes together, and butt the remaining ends of the cores, arrange the strands of each rope so that they interlock alternately with those of the other rope. Fig. 54 shows this stage of the process, though, for the sake of clearness, the ropes are farther apart than they would actually be.

4. Keeping the ends of the rope closely together remove the bindings, and let one man unlay a strand of one rope (see A, Fig. 54), while another man lays in its place the corresponding strand of the opposite rope, No. 1, until all but 6 in. of the strand are laid. Bind temporarily, and cut off the unlaying strand so that it is a foot longer than necessary to meet the end of the inserted strand.

5. Start on the opposite rope, so that the man who was laying is now unlaying. Unlay strand No. 2 and insert B in its place, finishing as before.

6. Take the next strand (C) of the rope on which work was originally commenced, cut 4 ft. off its end and lay it in the place of No. 3 in the opposite rope. Follow the same plan with the corresponding strand of the other rope. Unlay No. 4, lay D, temporarily securing the ends as before.

7. Lay in the last pair of strands, having previously cut 8 ft. off each. Three strands have now been unlayed in each rope and replaced by three strands from the opposite end. The lower view in Fig. 54 now represents the state of things, the overlapping ends of the strands are seen opposite the figures 1, 3, and 5.

8. The end of each strand is 12 in. longer than necessary to meet its fellow, each end being 6 in. longer than necessary to meet its fellow, and the only difficult part of the task is to dispose of these ends neatly. For rough work they may be gradually diminished in thickness and worked in under the strands as in ordinary rope, but the proper method is as follows:—

9. With a rope sling or blunt pipe tongs seize the rope about 9 in. on each side of the meeting of two strand ends. See O and P in the lower figure. Twist each part of the rope in the opposite direction to its lay to open the strands. Cut out 6 in. of the hemp core on each side of the strand junction, and with the help of the tongs force the strand ends into the space in the heart of the rope formerly occupied by the hemp core. See 2, 4, and 6 in the lower figure. Treat all the ends in a similar manner, hammer them gently with a wooden mallet, and after a few days' work the splice will be difficult to find.

The load to be hoisted may be carried in various receptacles, the bucket or "kibble" being the simplest; the latter is always barrel-shaped, the smaller diameter at the bottom and mouth assisting it in clearing obstructions, for the same reason the rivet heads on the outside are flush with the body. Requiring neither guides nor special road, the kibble is

largely used in winze and shaft sinking, and in all preliminary work. In vertical shafts it is kept clear of the timbering by lining the compartment with plank. In underlay shafts, bed planks are laid on which the kibble slides; the friction, however, is considerable, and increases as the angle departs from the vertical. Even in shafts already furnished with guides, the kibble is used for sinking, a travelling "monkey" being arranged to steady it in the hoisting ways (see Fig. 55); this monkey, or cross head, fits within the guides and rests on the shackle, the rope passes through it, but is not attached to it. A stop is fixed on the lowest guide, and on being lowered to this point the monkey rests on the stop, while the rope travels through it to the bottom of the shaft. On the return journey the monkey is again picked up by the shackle and travels to surface with the load. The arrangement may be seen within the guides in Fig. 55.

Kibbles are loaded either by hand, or from chutes into which the trucks tip; they are emptied by being lowered on to a fixed chain, which is hooked into a bow projecting from the bottom of the kibble. When used for baling water, a valve opening inwards is fixed in the bottom of the bucket; the valve opens on being lowered into the water, and is opened for discharging at surface when pressed inwards by a projecting pin, on to which the bucket is lowered.

Cages.—Although special cages have been devised for use on inclines, they are generally installed only in vertical shafts; they save handling the ore to a certain extent, as the truck and its contents are hoisted bodily to surface. Their use may be considered advisable when the ore has to be trammed some distance from the mouth of the shaft. It must be admitted that the dead weight on the engine is somewhat increased, but in double compartment shafts this is balanced by the descending cage.

Another disadvantage may be mentioned, the ore cannot be collected and stored beforehand in the shaft bins; the supply can only be hoisted as it arrives in the trucks from the chutes and faces, therefore the cage must wait in the mine for the trucks, or the trucks for the cage.

The size and shape of the cage are determined by the compartment in which it is to work, and the truck it has to contain. Generally it consists of a rectangular platform, furnished with rails to receive the truck; each corner of this platform is suspended from a wrought-iron rod, the four rods uniting with the corners of a frame about 7 ft. above the platform. This upper frame is provided with a hood opening upwards in two leaves, so that pipes, rails, and long timbers may be carried; four bridle chains connect it to the shackle on the rope. A simple catch prevents the truck from moving when the cage is in motion, and on each side of the upper and lower frames are clips to engage the guides.

Safety appliances are sometimes fitted to suspend the cage should it get disconnected, or the rope break; they consist of pointed levers or

toothed cams, forced by springs to grasp the guides, but held apart by the tension of the rope. No doubt these catches would be more generally fitted if they did not necessarily come into action each time the cage is resting on the keeps, and thus injure the guides at these points.

Skips.—These are used in any kind of shaft, vertical, inclined, or combined; they are specially suitable when the load has to be dealt with, or treated, at the mouth of the shaft. All skips are square, or nearly so, in section, and are generally arranged to dump automatically; rubbing strips protect the body from being worn by the guides, and clips retain it within the road. An average pattern will be 6 ft. long on the longest side, by 22½ in. square, and will hold 16 cub. ft. of ore; the bottom is made of steel plate $\frac{7}{16}$ in. thick, and the sides of ¼-in. steel plate. The body is attached to the bow so that it shall hang vertically, but it is neither necessary nor usual to place the guides in the centre.

For incline work, if the angle of underlie is regular, and is not less than 20° from the vertical, the weight of the skip is sufficient to keep it on the track, and rails may be substituted for the usual wooden runners. The wheels now take the weight, as well as the side friction formerly existing between the guides and rubbing pieces. It is curious to note that although mine trucks, which have to pass round the sharpest curves, are generally fitted with wheels fixed to the axles, yet loose wheels are supplied to skips running on a perfectly straight track. As the axle boxes are covered with grit at every loading, the wear and cost of upkeep are heavy. When working in incline shafts it will be found a far better plan to mount the skip bodily on axles to which the wheels are fastened, and let the axles work in bearings formed of hard-wood blocks bolted to the bottom of the skip. The bearing is now thoroughly protected from dirt, while the wood absorbs oil and grease, rendering frequent lubrication unnecessary. For self dumping the bow is extended to the rear, and the front wheels and axles made narrower than the back; the rear wheels keep to the main track and elevate the rear of the skip, while the narrower front wheels run between the main rails on to the track over the hopper.

Headgears.—The points for consideration about a headgear are, its height, strength, stability, and the materials to be used in its construction. The height will depend on the distance above the ground at which the load is to be delivered, while the winding speed and average skill of the drivers will decide the height of the sheave above this level.

The strength of the principal parts is based on the gross load and the speed of winding; but the same gear is often arranged to command the pumping compartment, and will be required to sustain the loads lifted by the capstan. Even in this case it will be found that, in securing rigidity against vibration, the strength is increased out of all proportion to the

FIG. 55.—Forty-five-ft. Headgear, for two Winding Compartments and Capstan.

[To face p. 138.

actual weight dealt with, as indicated by the various formulæ for strength of columns. But the strains on the headgear always exceed those due to the mere gross weight, as the load is a live one and subject to jars, surges, and other irregularities of motion. Then again, the stress on the rope is not vertical, but acts in two directions. Thus a racking strain is set up, to be met by carefully jointing the principals, and bracing the whole structure well together.

Stability is ensured when a line bisecting the angle made by the rope at the sheave falls to the ground within the base of the frame; should it meet the ground materially beyond this point, inclined stays are added, which practically extend the base of the structure. The form of headgear common in Australia is, to some extent, an exception to this rule, being so well braced internally that the resultant may safely fall without the base.

The materials to be used depend on local conditions. If timber in sufficient lengths is available it will probably be cheaper than an imported steel structure; the latter is generally built up of numerous small parts, any of them liable to loss in transit.

The simplest of all forms is the ordinary A frame, suitable for one winding compartment only; the strength of its principals may be found by the following rule:—The working load in tons is the side measurement of the timber in inches brought to the fourth power and divided by the length in feet squared. Thus, if each leg is 10 in. square by 40 ft. long, 10 by 10 by 10 by 10 divided by 40 by 40 equals 6.2 tons. As the frame is composed of two such legs it would support a weight of over 12 tons, and allowing for irregularity in motion, and for the fact that the legs are not vertical, might be safely worked with winding loads up to two tons. A frame of this kind will require stays to maintain it in the same vertical plane as the rope, and will need staying against the pull of the rope when the resultant falls beyond the base.

When the headgear is to cover a double compartment shaft, two of these frames are used, united by stringers at the top.

Fig. 55 illustrates a headgear of this kind, consisting of two main frames, one at each end of the shaft. Each frame consists of a sole piece, two legs, and a cap piece; the legs, 11 in. square, are tenoned at both ends, and the back ones are inclined, so as to dispense with back stays. It will be noticed that the position of the back legs brings the bisection of the rope angle well within the base. The foundations are laid by digging a trench 2 ft. deep under each sole piece, and filling it with broken stone, to allow for drainage. The wheel bearers rest on the stringers connecting the caps of the two frames; at the time the photograph was taken the cage road and bearers for one compartment were not in position. The frames were, in this instance, of an average height, 45 ft.; the extremes met with in general practice being 30 and 60 ft.

Headgears containing grizzlies, rock-breakers, and bins are more com-

plicated structures generally made of steel, the principal members being angle or tee iron 4, 5, or 6 in. wide. The four legs rest on cast-iron shoe plates, supported by masonry or concrete piers. In smaller sizes the frames are put together on the ground and hoisted into position, the sling chains being adjusted to take the weight in two or more places; this precaution is necessary as the skeleton structure can hardly stand its own weight when placed horizontally, or at an angle approaching the horizontal. Examples of steel headgear are given in Fig. 56.

Heavier headgears are built up in floors from the ground level, the bracing of each floor being completed before the next is added. A steel plate, through which the rope passes, is built into the frames near the wheels to operate the detaching hook and support the cage in case of overwinding.

In flat underlie shafts the headgear is almost an extension of the skiproad supported on trestle work; and in very flat shafts the rope is merely passed over a roller at the brace and attached directly to the mine trucks.

The sheaves must stand vertically, and in exactly the same plane as the rope, otherwise friction occurs between the rope and pulley, and the former suffers. After the sheave has been levelled and centred over the cage road by plumbing, perhaps the easiest method is to sight along its edges to chalk marks on the drum, but this must be done from different points of the circumference, as the rims themselves may not be quite true; or sights may be taken along two plumb lines hung, on opposite sides of the wheel, in the V groove.

[To face p. 140.

Table of Inclines.

Number of Degrees.	Inclination per Yard, in Inches.	Equal to one in	Pull on Rope per Ton of Load, in Pounds.
1	57.29	0.63	39.08
2	28.63	1.26	78.18
3	19.08	1.88	117.24
4	14.30	2.51	156.26
5	11.43	3.15	195.24
6	9.51	3.78	234.14
7	8.14	4.42	272.98
8	7.11	5.06	311.74
9	6.31	5.70	350.40
10	5.67	6.34	388.97
11	5.14	6.99	427.41
12	4.70	7.65	465.71
13	4.33	8.31	503.88
14	4.01	8.97	541.90
15	3.73	9.64	579.75
16	3.48	10.32	617.43
17	3.27	11.00	654.90
18	3.07	11.69	692.20
19	2.90	12.39	729.27
20	2.74	13.10	766.12
21	2.60	13.82	802.74
22	2.47	14.54	839.12
23	2.35	15.27	875.23
24	2.24	16.02	911.09
25	2.14	16.78	946.66
26	2.05	17.56	981.94
27	1.96	18.34	1016.93
28	1.88	19.14	1051.61
29	1.80	19.95	1085.97
30	1.73	20.78	1120.00
31	1.66	21.62	1153.68
32	1.60	22.49	1187.02
33	1.54	23.37	1219.99
34	1.48	24.28	1252.58
35	1.42	25.20	1284.81
36	1.37	26.15	1316.62
37	1.32	27.12	1348.05
38	1.28	28.12	1379.07
39	1.23	29.14	1409.67
40	1.19	30.21	1439.84

CHAPTER IX.

AIR COMPRESSORS.

Air Compression, Cooling and Reheating—Air Valves—Walker Compressors—Ingersoll-Sergeant Compressors—Erecting—Receivers—Mains—Amount of Air Required by Rock Drills.

THE work on an ore body cannot be concentrated entirely on one spot, as it is only by having numerous points of attack that sufficiently rapid progress can be made. On every mine, therefore, a demand exists for motive power for distribution to these more or less isolated points of operation; the media chiefly used are compressed air and electricity, and if the scheme is to include the underground workings, the former has distinct advantages.

Compressed air is easily and cheaply stored; there is no danger of fire or shock; no change in equipment is necessary, the same steam motors and pipes being used; and in underground workings the exhaust ventilates and cools the mine.

With the assistance of this exhaust air tunnels may be driven, unconnected with other workings, for distances quite impracticable without some system of artificial ventilation. If similar work be attempted by hand labour the rate of progress rapidly diminishes when the heading has advanced a few hundred feet, the gases take a longer time to clear after each blast, until driving has to be suspended while a connection is made with some other working. This connection may serve scarcely any useful purpose but ventilation, so that its cost might fairly be debited to that of the original heading, to say nothing of the time lost in its construction. It is not always recognised what an important factor time is, especially on a foreign mine where the standing charges are necessarily high. Take, for instance, a mine in the early development stage, with a monthly advance of 250 ft. and standing charges of £250; these costs including management, office, agencies, pumping, and other expenses unavoidable as long as the mine is not shut down. This amount represents £1 on each foot driven; but if by rock drills, or other means, the footage is doubled, the standing costs per foot are halved.

Just as combustion was discussed before going on to steam and steam motors, so perhaps it will be advisable to briefly recapitulate the behaviour

of air and gases under compression, before passing on to the means by which the compression is effected.

In common with other gases, the volume, the pressure, and the temperature of air tend to remain constant, and if this equilibrium is destroyed by an alteration of one of these conditions, one of the others must change also. The next feature to note is, the product of the pressure and volume is constant; therefore one varies inversely with the other.

It is evident then that, since both pressure and volume are altered in the process, air cannot be compressed without increase of temperature, nor expanded without loss of temperature. But these are the relative functions of the compressor and motor, the one to compress, the other to expand; in each case temperature is involved, and is an important factor, the compression being best when the heat is kept low, and expansion best when it is kept high.

There is a great deal of misconception on this point, and the air system suffers accordingly; a steam-engine admittedly works by heat, because the steam is hot, but an air motor is supposed to work in some miraculous way by pressure. Heat is involved as directly in one case as in the other, and the work done is proportionate to the difference in temperature between the air admitted to, and that exhausted from, the motor. The air may be less hot than the steam, but the difference between the admitted and exhausted gas will be the same in each case provided equal work is done; the ordinary rock drill works with scarcely any expansion, and yet its exhaust is often below zero.

To get a clearer idea of the principles involved, let us trace an imaginary compression stroke in a cylinder so thoroughly cooled that the air cannot increase in temperature. The compression now follows Boyle's law, when half the stroke is completed the air will be halved in volume and doubled in pressure; and when the volume is reduced to one-fourth the pressure will be increased four times. Compression on such lines as these would give a maximum result for a given expenditure of power, and an indicator attached to the cylinder would trace an isothermal curve.

Let a stroke now be made in an uncooled cylinder formed of some non-conducting substance which retains all the heat arising from the compression; when compressed to half its original volume the air will be at double the original pressure plus an additional amount of pressure due to the heat contained. This heat represents an expenditure of about 30 per cent. more power than the previous example; such a compressor would give a minimum result for the power applied, and its indicator would trace an adiabatic curve.

In actual practice no cooling is perfect, no cylinder a non-conductor, and the indicator pencil traces a line between the adiabatic and isothermal curves, as shown in Fig. 57. The additional heat imparted to the air in a

badly cooled compressor would be advantageous rather than otherwise, provided the air was used while still hot, but this is never done; it is stored in naked receivers, conveyed through naked pipes, and since the heat is not utilised, it represents power wasted. In recent years much has been done towards minimising this loss by means of stage compression and intercooling; but the first step in this direction consists in supplying cool air to the compressor inlets. The colder the air, the more efficient the compression, and every degree of heat abstracted is just as important as those added to feed water or to superheated steam; a reduction of 5° in the temperature of the air admitted is equivalent to an increase of 1 per cent. in the capacity and efficiency of the compressor. When the entering air is cold the relative increase of heat during compression is less than with warm air; the author has satisfied himself on this point by running uncooled and unjacketed compressors with very fair efficiency, as long as the entering air was between freezing point and zero.

In the face of these facts, what is the general custom? Is it not to take air from the engine-room, where it is several degrees hotter than the outside air? In hot climates even outside air may generally be reduced in temperature by some simple arrangement of water dripping over pipes, or, since no pressure is involved, by passing the supply through some discarded cooler or condenser.

In stage compression the work is divided between two or more cylinders, and as the pressures used in mining work do not exceed 80 or 90 lbs. per square inch, two-stage compression is generally employed. The advantages of this system are numerous: (1) the compression is less rapid, more time being taken to compress a given quantity; (2) each cylinder is subjected to less variation in temperature; (3) there is less difference in the pressure on opposite sides of valves and pistons; (4) the clearance in the high-pressure cylinder is of less cubic capacity; (5) the air can be cooled in its passage from one cylinder to the other.

In the single-stage system, when compression is completed in one cylinder, the parts in contact with the air are more highly heated than they would be if the compression were only carried to half the extent. Part of this heat is abstracted by the next incoming charge, and the cylinder is filled with heated, and therefore rarefied, air. The water jacket keeps the heat of the cylinder itself within reasonable limits, but has little effect on the charge, since only the outer ring of air is in contact with the cooling surface.

The centre part of the charge does not part with its heat; in any case the heating is so instantaneous and air such a poor conductor that the duration of the stroke affords no time for abstraction of the heat.

In two-stage compression, the charge from the low-pressure cylinder passes through an inter-cooler on its way to the high-pressure side. Here its temperature is reduced, but as the pressure remains constant, the volume

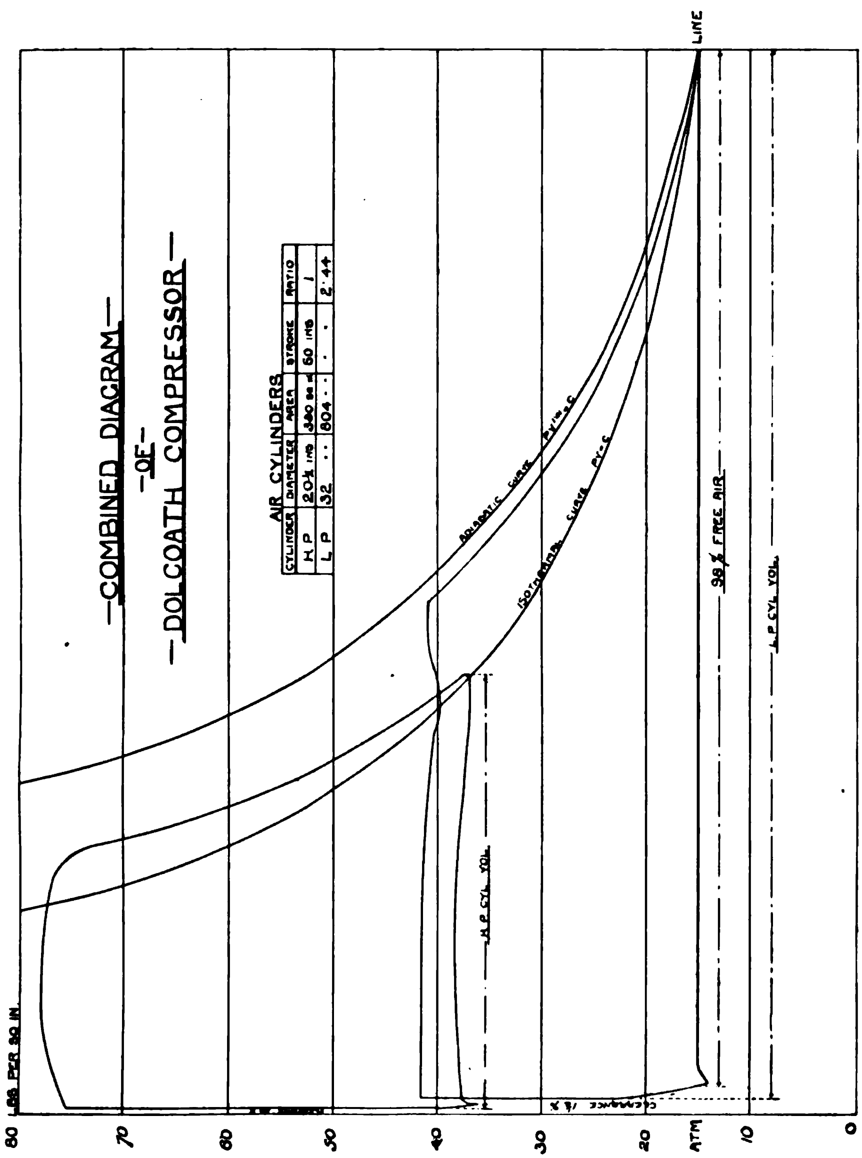


FIG. 57.—Diagram from High and Low Pressure Air Cylinders of Holman Brothers' Compressor at Dolcoath.

must vary in accordance with the laws already quoted; the result is, the high-pressure cylinder receives a charge diminished both in temperature and volume.

Clearance between piston and covers is essential in every cylinder, and

as the length of clearance is nearly constant, the cubic capacity will vary with the size of the cylinder. This space is filled with air at maximum pressure, and is larger in the single-stage compressor than in the small high-pressure cylinder of the compound system. It is true the latter system has two cylinders, each with clearance spaces, but in the low-pressure side this space is filled with air at only half the total pressure.

The actual result of these advantages is an economy of about 20 per cent. in favour of the stage system.

A compressor is necessarily affected by the pressure of the external air as shown by the barometer; the air being lighter as the altitude increases, the engine delivers a decreased volume per stroke, or requires larger cylinders to deliver a given volume. The volumetric efficiency decreases about 3 per cent. for every 1,000 ft. above sea level; as the resistance is less, the motive power required is also less, and decreases about $1\frac{1}{2}$ per cent. for every 1,000 ft. of altitude.

When considering steam, it was noted that the heat required to produce a given increase in pressure decreased as the total pressure increased; the same thing happens with regard to air compression, the heat losses decrease and the power is applied to better advantage at high pressures. About $8\frac{1}{2}$ H.P. are required to compress 100 cub. ft. of air to 30 lbs. per square inch; but this same power, if applied to air at 30 lbs. pressure, would raise it to 90 lbs. per square inch. Thirteen and a half H.P. are required to compress 100 cub. ft. of free air to 60 lbs. per square inch; but the same power applied to air at 60 lbs. increases the pressure to 350 lbs. per square inch.

There is in each case a diminished volume to work with, and these high pressures only show to advantage when used in compound motors, for in this class only can the exhaust be reduced to anything approaching atmospheric pressure.

It is useful to remember that each 100 cub. ft. of air delivered per hour at 60 lbs. per square inch represents one H.P.

Precautions are taken to avoid heating the air in compression, mainly because that heat is afterwards lost; but the air may, with great advantage, be heated before being used, especially as the volume is augmented with every increase of heat. The same quantity of heat that raises 1 lb. of water 1° Fahr. raises 1 lb. or 13 cub. ft. of air 4°; the heat, therefore, is applied to better advantage even than in a boiler. The apparatus for reheating is of the simplest description, a coil of pipe, a nest of tubes, or an old boiler, will enable the air to be heated to 300° Fahr. with a very small quantity of fuel. Care must afterwards be taken, by covering the pipes and other means, to prevent this heat from being lost; this usually implies that the reheater is placed close to the motor. For example, let the air be at 60° Fahr., and 90 lbs. pressure, if the temperature is increased by 240° the volume is increased 46 per cent.; if the air were heated to 350° the volu-

metric increase is 55 per cent.; hence a double advantage results, more air, and a temperature permitting that air to be used expansively.

The following example of reheating occurred at a mine in the author's charge, where a direct-acting pump was employed on a lift of 600 ft., power being supplied by a boiler steaming both winding engine and pump. A compressor driven by water power was installed, and as air was cheaper than coal, the mains were connected to the pump, enabling it to be driven either by steam or air.

As the steam pressure exceeded the air pressure by a few pounds, the two were mixed just before admission to the pump; although the amount of steam admitted was only that due to $\frac{1}{10}$ of a turn of a $1\frac{1}{2}$-in. wheel valve, the pump raced away as though the pressure had been considerably increased. It was found possible to work another rock drill even when the pump was going, and the quantity of steam used was so small that the boiler attendant did not know the valve had been opened. Unfortunately press of other duties prevented an exact determination of the economy effected.

As a dynamo, by reversal of current, becomes a motor, so a steam-engine may become a compressor—the action may be noticed in a locomotive running light downhill; as originally made, compressors were ordinary steam-engines with air cylinders attached. At first sight it might appear that an engine working with 90 lbs. of steam is subject to the same strain as a compressor delivering at that pressure; but the massive build of a well-designed compressor points to a different conclusion.

In the engine the piston is receding from a decreasing pressure, in the compressor advancing against an increasing resistance; in the engine the load resists going forward, in the compressor it actively pushes backward; and in the latter the maximum steam and air pressures occur at opposite ends of the stroke, one being highest when the other is lowest, the balance being transmitted through the bed-plate and connections.

Such strains cannot be taken by an ordinary base-plate. They demand a girder frame with straight line resistance in the same plane as the piston rods, and the utmost support a solid foundation can afford. A compressor driven by steam is complete in itself, and consists of a steam-engine with air cylinders attached; but motion may also be derived from a crank shaft driven directly by an impact wheel, or by belts, ropes, or gearing from any hydraulic or electric motor. In detail the chief difference in compressors lies in the control of the air valves, which may be effected either by springs, by air pressure on pistons, or by motion derived from the motor, the last variety having a positive action.

In small compressors the inlet and outlet valves are generally controlled by springs; as the inlets are horizontal, the spring, in addition to overcoming the friction due to the weight of the valve, must be strong enough to close it sharply. That this spring tension is not a negligible

quantity when multiplied by the area of the piston and its stroke, is proved when the inlet springs are even slightly tightened on an ungoverned compressor; the revolutions per minute at once decrease.

The outlet valves are forced upward by the pressure beneath, and downwards by the air pressure and spring tension above. While air is passing through them they are in a state of unstable equilibrium, chattering on their seats, so that three or more distinct beats may often be heard. The result is seen in the wavy discharge line in the diagram, and wear on the valves and their seatings. Lastly, in order to use springs of reasonable strength the valves must be light and small, consequently they must be numerous, and this often leads to equally numerous pockets and enlarged clearance space.

It will not be necessary to discuss the merits of the various mechanically controlled systems. The best known, if not the parent idea, is the Riedler, and the valve action has already been described in Chapter VII. Some very fine compressors with these valves have been erected in South Africa, but detailed descriptions of the many different makes in use would be mere catalogue work. It will be sufficient to refer to typical engines of English and American manufacture, and the Walker and Ingersoll-Sergeant machines have been selected for this purpose. Each of these firms makes a speciality of this class of work, and it would be as reasonable to order a locomotive from a marine engine builder, as a compressor from a firm who have not made a study of this type of engine. Although each of the above firms can and do make compressors in all sizes, in mining work Messrs Walker Bros. are best represented by their heavy installations, and the American firm by the excellence of their smaller engines, which can be delivered from stock.

The Walker Compressors will be found on almost every important goldfield in the world, large numbers being in use in South Africa, India, Australia, and Canada. They are made in sizes up to 3,000 I.H.P., in different arrangements and combinations of steam and air cylinders. For large installations they are supplied duplex, compound, condensing, with Corliss gear, and single or multi-stage compression. For smaller equipments a single half may be erected first and converted into a duplex by the addition of a second side at a later date. Great strength of parts and ample wearing surfaces are found in each pattern, but the peculiarity of the Walker engine lies in the air valves and their method of control. On each cylinder cover there are two of these valves, one for inlet and the other for delivery. The area of each valve is about one-third that of the piston, and when closed, it fills the recess in the cover in which it works.

These valves somewhat resemble the clacks used in pitwork, they are freely suspended from hinge pins at their upper ends, and tend to close by

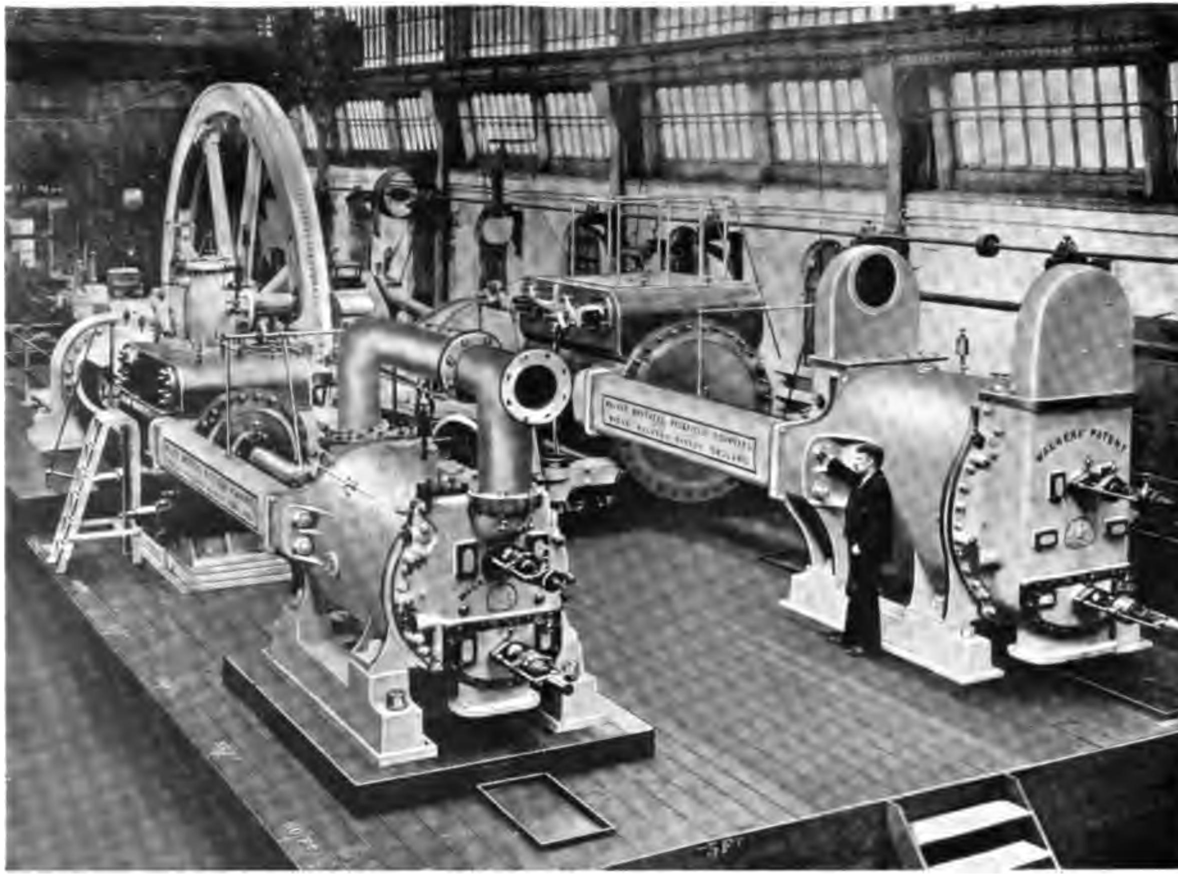


FIG. 58.—Compound Corliss Two-stage Walker Compressor. Low-pressure steam cylinder, 64 in.; low-pressure air cylinder, 58 in. Steam pressure, 140 lbs.; air pressure, 80 lbs.

[To face p. 148.

their own weight. The beats are metal to metal, but as the last fraction of an inch of closing is controlled by a cushioning arrangement, the meeting of the valve with its seat is practically inaudible. Both inlet and outlet valves are made of steel, and lift with a silent swinging motion, freely following the movement of the piston and the air pressure. The closing is assisted by a light coiled spring adjusted by milled nuts, and exerting such slight pressure on the valve, that in the largest engines there is no perceptible difference in the diagram between the induction and atmospheric lines.

Beyond lubrication of the hinge pins and occasional cleaning, these valves need no attention even after many years of constant work. About 300,000 I.H.P. of these compressors have been built, in all sizes up to 72-in. air cylinders. When arranged for condensing, the air pump is worked by an extension of the piston rod, or, with the condenser, forms a separate installation.

Under tests made while at work on a mine the consumption of a pair of compound two-stage Walker compressors was found to be 1.54 lb. of coal per I.H.P. per hour when condensing, and 2.35 lbs. when non-condensing.

As evidence of the material and workmanship put into their machinery, Messrs Walker Brothers are able to refer to one of their winding engines in use about a quarter of a century, which has hoisted 20,000,000 tons of coal from a depth of 1,200 feet.

The Ingersoll-Sergeant compressors are perhaps best known in what is called the "A" class, in which the working parts are mounted on a deep box-bed so massive that most of the usual foundation is dispensed with. The centre of the engine is kept low, level with the top of the bed, the crank shaft is placed at the end of the steam cylinder, and side rods connect the crank pins to a long cross-head working between the steam and air cylinders.

After testing mechanically controlled and other valves, the Company still retain their original piston inlet valves. These consist of two plain rings working in the body of the piston; they are uncontrolled by springs and work entirely by air pressure and momentum. This arrangement permits the cylinder covers to be water jacketed, and cooling applied where it is most effective; while the system of drawing the air supply through the hollow piston rod facilitates a supply from outside the engine-house.

Fig. 59 is a longitudinal section through the air cylinder, the solid piston rod being attached to the cross-head, and the air entering through the hollow extension to the rear. It will be seen both ends and body are well jacketed; the air valves are shown at G G.

Suppose the piston to be at one end of its stroke, when it has moved sufficiently to allow the small quantity of air in the clearance spaces to

expand, the valve will open, being left behind by the advancing piston. Before the first quarter of an inch in the stroke is completed, the valve on the opposite side will be closed. Thus the advancing valve is always shut and the receding one open. This action works regularly at speeds as slow as nine revolutions a minute, while the clearance spaces are small, a ring being cut in each cover to receive the projecting rim of the valve.

The Company manufactures about forty different types, ranging from

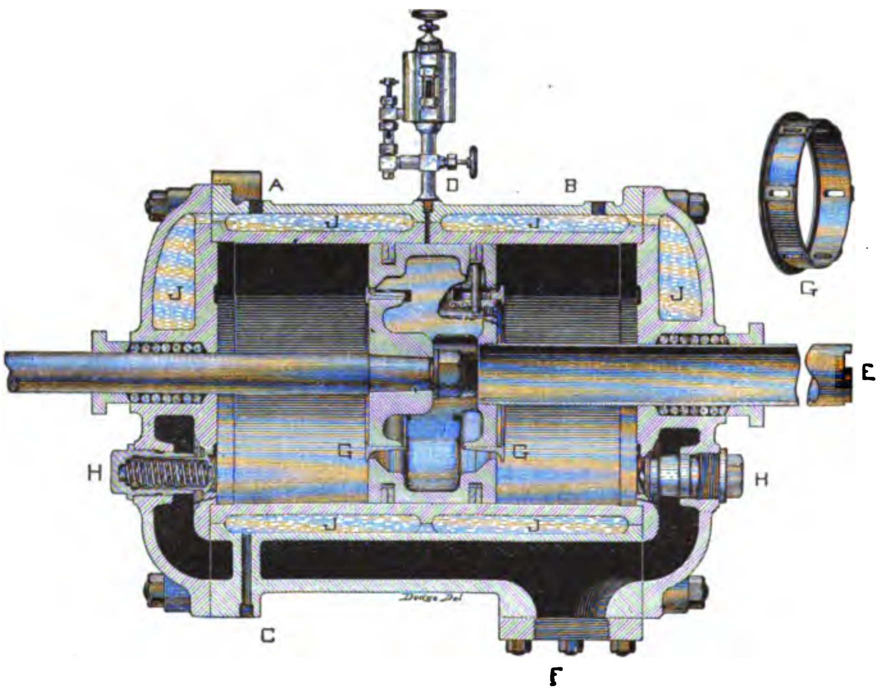


FIG. 59.—Section through Ingersoll-Sergeant Air Cylinder.

the simple straight line "Class A," to Duplex Compound Corliss machines; many of the patterns are arranged for belt driving, others to be worked by electricity. A special type of engine, used for charging pneumatic locomotives, compresses by the three-stage system to 8,000 lbs. per square inch.

The following table contains some useful particulars of the "Class A" machines, arranged for a steam pressure of 80 to 100 lbs. per square inch, the capacity being calculated for sea level; reduction must be made for altitude as already explained.

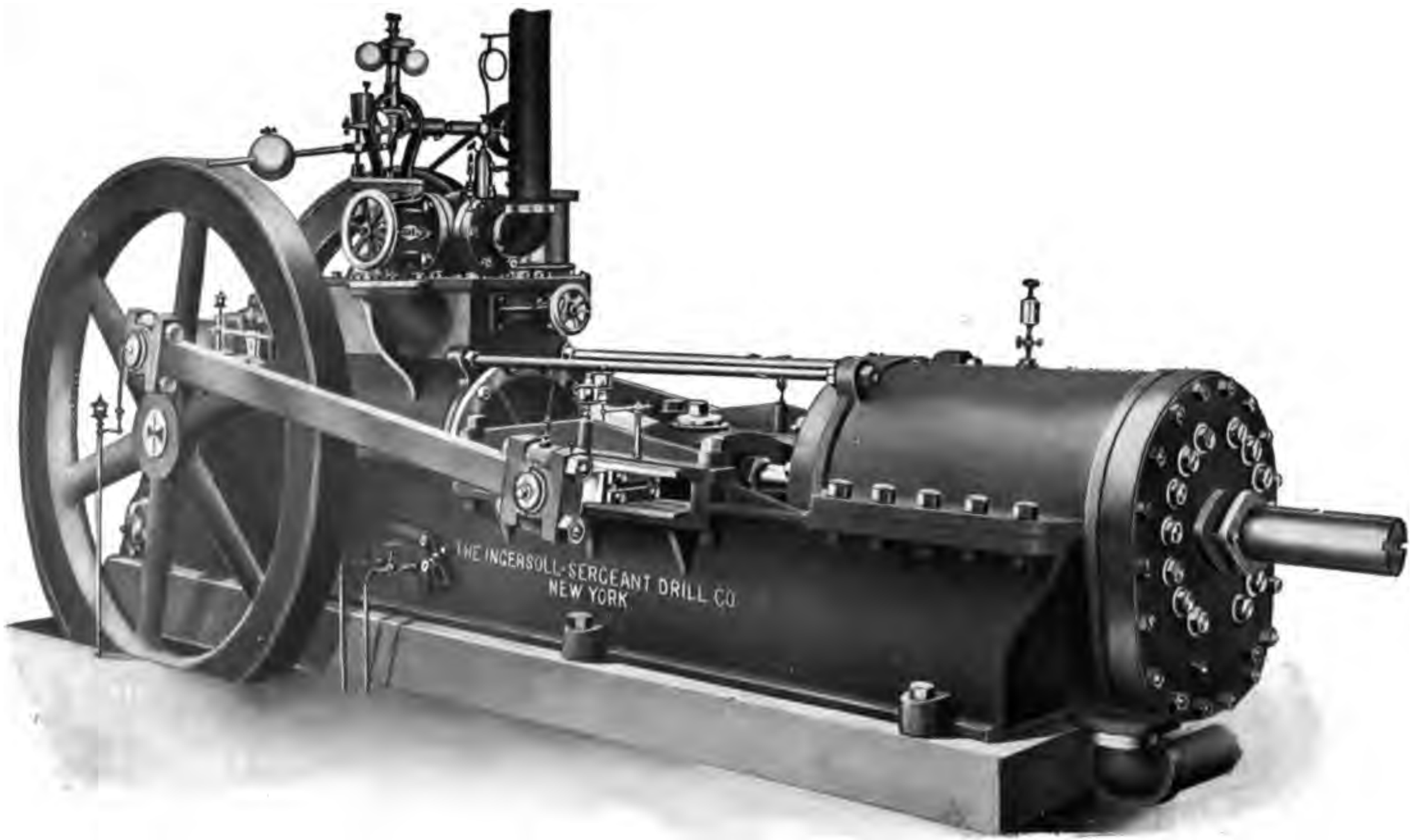


FIG. 60.—Ingersoll-Sergeant Straight-line "Class A" Compressor.

[To face p. 150.

INGERSOLL-SERGEANT STRAIGHT-LINE COMPRESSOR.

Diameter of Cylinders.		Stroke.	Revolutions per Minute.	H.P.	Cubic Feet of Free Air.	Air Pressure.	Air Main.	Weight Packed.
Steam.	Air.							
Inches.	Inches.	Inches.					Inches.	Lbs.
10	10¼	12	160	35	177	100	3	5,100
10	12¼	14	160	37	252	60	3½	5,200
12	12¼	14	155	57	285	100	3½	9,800
14	14¼	18	120	76	381	100	3½	14,700
14	16¼	18	120	91	498	85	4	15,100
16	16¼	18	120	100	498	100	4	15,700
18	18¼	24	94	131	656	100	5	24,200
18	20¼	24	94	155	807	90	5	24,700
20	20¼	24	94	161	807	100	5	25,200
22	22¼	24	94	194	973	100	5	26,200
22	24¼	24	94	204	1,150	80	6	26,700
24	24¼	30	80	242	1,223	100	6	39,200
24	22¼	30	80	235	1,035	125	6	38,500
24	26¼	30	80	252	1,444	80	7	39,700

Though the loadings will probably be heavier, built in the soundest possible manner, with the engine rigidly connected to it by numerous anchorage bolts, yet the erection itself does not differ from that of an ordinary horizontal engine, the principles of which have already been explained. The water service for cooling is a feature demanding special attention; in gas and oil motors the amount of cooling need only be sufficient to prevent excessive heat in the cylinders, consequently the water may circulate, and be used again while still warm. For air compressing a constant supply of water is required, the colder the better; one advantage in driving compressors by hydraulic power lies in the abundant cooling water available. The service pipes are arranged that the water enters at the bottom of the jackets and leaves at the top, the overflow being usually further heated and used for feed.

Intercoolers also require a constant supply, and under favourable conditions, with ample water and cooling surface, the temperature of the air supply to the high-pressure side should not exceed that of the surrounding atmosphere. The average quantity of cooling water required is 6 cub. ft. per 500 cub. ft. of free air dealt with. The steam supply is preferably regulated by the air pressure, any decrease in pressure admitting more steam to the engine. The recording pressure gauge is a useful fitting, not only as a check on the engine-room staff, but for settling the endless disputes between the surface and underground men, the latter, especially when on night-shift, being prone to make "low air" an excuse for every deficiency.

Lubrication of the air cylinders is an important matter, an unsuitable oil soon forming a semi-carbonised deposit on pistons, covers, and valves, and in this way fills the clearance spaces, already reduced to a minimum for the sake of efficiency. This deposit of burnt oil happens to be an excellent non-conductor, a very thin coating interfering seriously with the cooling effect of the jackets. A good quality of gas-engine oil will be found satisfactory for internal use, but in any case the surfaces will require cleaning occasionally; negligence in this respect has led to broken bed-plates on more than one occasion.

The tightness of most inlet valves can be tested by painting their faces with soapy water while at work; leaky outlet valves will tighten the inlets on their seats if the engine is standing under pressure; diagrams should be taken at regular intervals from both steam and air cylinders.

To find the quantity of air delivered at a given pressure, multiply the displacement of the piston in cubic feet per minute by the following constants:—

Air pressure in lbs. per sq. in.	30	40	50	60	70	80	90	100
Constant	0.332	0.275	0.232	0.21	0.185	0.165	0.15	0.133

Owing to the heat generated in compression the quantity of air actually delivered to the receiver will be slightly in excess of that given by this formula.

Receivers.—From the engine the air passes to the receiver; this is simply a reservoir, the shape being immaterial, as long as it is strong enough and free from leakage. As the demand for air is a constantly fluctuating one, varying with the number of machines at work, it is in every way economical to have ample storage capacity.

Disused boilers may be pressed into service for additional receiver space, while an air main of ample diameter adds to the storage capacity and diminishes frictional losses. The receiver fittings consist of stop valve to the main, safety valve, pressure gauge, and drain tap; the pipe connections should be so arranged that the air does not enter and leave the receiver at the same point, as during its stay in the receiver much of the surplus moisture will be deposited. To facilitate drainage of this water, it is well to raise the receivers a foot or more clear of the ground.

Air Mains.—As stated above, a large main prevents friction and affords storage space; useful effect may be, and usually is, lost through adopting a minimum size for the work required.

The resistance the air meets with in its passage through a pipe is

inversely as the length, directly as the diameter of the pipe, and directly as the square of the velocity.

For horizontal and incline work an excellent pipe is made with loose male and female flanges at the ends; the extremities of the pipe are beaded outwards for a quarter of an inch after the flanges are on. Such pipes are not weakened by screw threads and are very light; they are easily cut to lengths required, and flanged in dies supplied for the purpose. For vertical shafts fixed flanges are preferable.

In laying down the main, cross pieces should be left at each level and tee pieces at every cross cut, with valves in each case to cut off the distribution pipe supplied; the gate valve allows a clearer passage but is more difficult to repair and keep tight than the ordinary wheel valve. The main should extend at least a length of pipe below the lowest connection and be fitted with a trap or drain tap at its lower end.

Two-inch wrought-iron pipe is generally selected for distribution work in levels; nothing is saved by using $1\frac{1}{2}$-in. pipe, except a trifle in first cost, and an unnecessary complication in sizes is introduced. Towards the face, the 2-in. pipe gives place to 1-in., which is laid temporarily as the heading advances.

As pipe laying and jointing form the subject of a separate chapter, it will be sufficient to say that a properly laid air main and connections should show no fall of pressure after many hours' test. It is easier and more satisfactory to bring this about by careful laying than by seeking out and remedying leaks after the installation is completed. When the working pressure is 80 lbs., a hole $\frac{1}{64}$ in. in diameter allows a cubic foot of air to leak through every three minutes. Efficiency at surface is useless if the mains and connections are faulty, the most troublesome parts to keep tight being generally the hose connections and the temporary 1-in. piping laid as the face advances.

All connections should be tested at regular intervals, say once a month, and a record kept of their performance; as it might interfere with the mine work if the mains were closed for several hours, it will be sufficient to shut all terminal cocks and note the number of revolutions the compressor has to make in ten minutes to keep the pressure constant. Suppose the ordinary speed of the compressor is 100 revolutions a minute, and with outlets shut it takes 50 revolutions in ten minutes to keep the pressure constant, the leakage is then 5 per cent. of the total amount supplied.

The following table gives the capacity of various pipes in cubic feet of air per minute, at different pressures, the loss of pressure being limited to 1 lb. on the square inch :—

Air Pressure, in Pounds per Square Inch.	Bore of Pipe.										
	1 in.	1½ in.	2 ins.	2½ ins.	3 ins.	3½ ins.	4 ins.	4½ ins.	5 ins.	6 ins.	7 ins.
60	16	48	107	193	315	471	668	905	1,180	1,890	2,810
75	18	53	117	212	346	517	734	994	1,300	2,080	3,090
90	19	57	127	229	375	560	794	1,070	1,410	2,250	5,340
	Cubic feet per minute.										

Average Number of Cubic Feet of Free Air Required to run one Rock Drill at Different Pressures.

Gauge Pressure.	2 ins.	2¼ ins.	2½ ins.	2¾ ins.	3 ins.	3⅛ ins.	3¼ ins.	3⅝ ins.	3¾ ins.
60 lbs.	50	60	68	82	90	95	100	113	120
70 ,,	56	68	77	93	102	108	113	130	135
80 ,,	63	76	86	104	114	120	127	142	150
90 ,,	70	84	95	115	126	133	141	159	167
100 ,,	77	92	104	126	138	146	154	175	184

CHAPTER X.

ROCK DRILLS.

Types—Holman and Ingersoll-Sergeant Drills—Mounts—Bits—Drilling—Rotating Drills—Electric Drills—Sharpening and Hardening Bits—Diamond Drills—Erecting—Running—Deflection in Bores—Deep Bores—Table of Sullivan Machines and Derricks.

Of the many forms of rock drills, the percussive air-driven machine is practically the only one used in the boring and blasting part of gold-mining work. It is not necessary to refer to the hand machines which, in various patterns, have been on the market thirty years or more. In most of them the drill is drawn back by a revolving cam, and propelled against the face by spring pressure; but after turning the handle a few minutes one is reminded the human machine is at its worst in continuous effort, and best when used intermittently, as with oar or hammer.

The air-driven drill is seen to greatest advantage in hard, homogeneous ground, free from slips and flaws; but it has already been pointed out that machine work may be economical even when the cost per foot exceeds that of hand labour. The drill is essentially a time saver, and in comparing the cost of hand and machine work the time factor must not be neglected. There is often a saving in labour too, perhaps not in the number of men employed at any one time, but in the total number of days worked for a given advance.

The features desirable in a rock drill are reliability, dead blow, variable stroke, portability, compactness, protection and interchangeability of working parts, and provision for taking up wear. Most machines combine these points to a certain extent, while no drill excels in all of them.

Nor does any great difference exist in the arrangement of the machines, except in the valve action. Valves may be operated in three different ways—(1) by the contact of a rocker or tappet with the main piston; (2) by the same medium as the drill itself, air or steam; (3) by a combination of these methods.

Without reference to any particular make of machine, but merely comparing the three valve actions, it might be advocated that the first is the most reliable and certain in its action; the second, lightest in upkeep

and repair; the third strikes the deadest blow and admits greatest variation in length of stroke.

Having had a good deal to do with these machines, tried over twenty varieties, and run over forty on each shift, the author is obliged to admit that, in his opinion, the American drill is often superior both in workmanship and material to the English. The reason may be that the drill in this country is a sort of bye-product of ironworks engaged on other machinery, while in America it is made a speciality. There the parts are hardened and ground to fit, joints require no packing to make them tight, and duplicate parts need not be machined to fit after their arrival on the mine.

It is patent that the rock drill has to fulfil numerous requirements, many of them so conflicting that a compromise is the only possible result. For instance, it must strike a dead, uncushioned blow, and yet work with a variable length of stroke; but to comply with the latter condition the valve must be capable of reversal before a long stroke is completed. It must be strong enough to stand rough usage and yet be light as possible. This means the factor of safety must be cut fine to ensure portability; for it is one thing to carry 2 cwt. on a turnpike road, and quite another to drag the same weight up a steep, slippery stope. Compactness is equally essential, as the angle that can be bored in a confined space is chiefly decided by the over-all dimensions of the machine.

In any drill with a fairly uncushioned stroke, the force of the blow will depend on the diameter of the piston, the air pressure, length of stroke, and weight of piston rod and bit. Naturally, the diameter of the cylinder is the chief factor in determining both the force of the blow and the weight of the machine.

The size of machine to be used at any particular point is often decided by the weight and the facilities for handling the weight. In sinking a shaft the drill can be controlled by a winding engine or winch, and a 3½-in. or 4-in. machine may be used. For driving, a 3-in. or 3⅛-in. would be sufficiently heavy; while in stoping a still lighter one is required. Such an arrangement would be practicable when a depot of spare parts is close at hand; even then difficulties would arise. There must be spare machines of each size on hand, three different sizes of supports, hoses, and bits, and such things seem to have a knack of getting supplied to the drill they won't fit.

On most mines it is found preferable to adopt one medium size, all-round machine, say a 3-in. cylinder, weighing about 240 lbs.; and to use one make and one pattern in order to keep the stock of spares within reasonable limits.

In all machines the cylinder is supported by an adjustable cradle, and fed forward by a screw as the hole deepens. The piston rod at its rear end carries a rifle nut engaging with a twist bar; this bar is held by ratchet gear on the backward stroke of the piston, and causes a partial rotation of

the drill bit. The exact amount of turn imparted depends on the length of stroke; the longer the stroke the greater the rotation, a complete revolution being made in about six full strokes.

At the front of the piston rod is the chuck for carrying the bits. This may be taper, in which case the blunt bit is knocked out by a drift; or parallel, when the bit is secured by a U bolt. Each method has advantages, the taper chuck is simpler and cheaper in upkeep. But in hard ground it is rather too rigid a fastening, leading to broken shanks and piston rods when glancing blows are struck. When the drill chuck is an enlargement of the piston rod, the front cover is made in halves. Cup leather rings in the stuffing-box prevent leakage around the rod.

There is considerable difference in the area of the two sides of the piston, the forward stroke is made under air pressure on the full area, but on the backward stroke pressure is only applied to the difference in area between the piston and rod. It is plain, therefore, that, under given con-

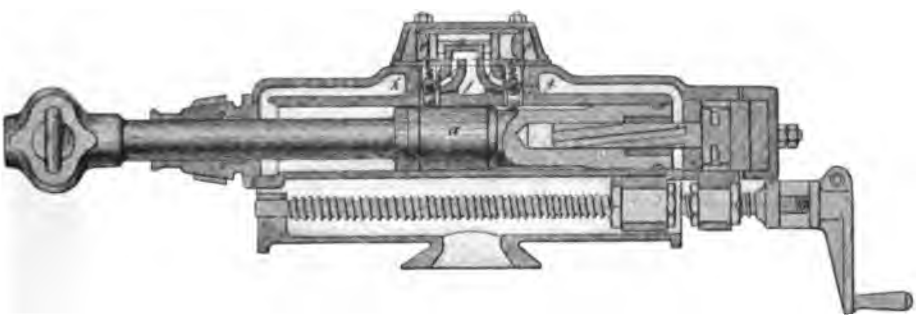


FIG. 61.—Holman Air Valve Drill.

ditions, the power of the machine to "mud" or withdraw after the blow is largely affected by the diameter of the piston rod.

Excepting those machines working on the compound system, which economise air at the cost of increased weight, the differences exist in detail only; and sufficient idea of the general arrangement of the mechanism will be afforded if three or four types are illustrated.

Fig. 61 is a section of a Holman drill with air-driven valve. The slide valve is carried by a small piston, to which air is admitted by two ball valves. These balls, made of hardened crucible steel, are worked by inclined shoulders on the body of the piston, and serve to release the air from the end of the small piston. The machine is made with $2\frac{1}{2}$-in., $3\frac{1}{4}$-in., $3\frac{1}{2}$-in., and $3\frac{5}{8}$-in. cylinders. The valve motion is of hardened steel, and the stroke may be varied from 1 to 7 in.

The machine illustrated in Fig. 61 is fitted with a clutch for parallel shank drills, and a reversed cone fitting to the clamp; the alternative

arrangement is shown in Fig. 62 of Holman Brothers' tappet drill, arranged to take taper shank bits.

This drill is made in the same sizes as the air valve machine; the slide valve is worked by a rocker, operated more by sliding contact than by impact, with the ball formed on the piston. The movement of the slide valve admits air to the cylinder ports, as in an ordinary engine; the exhaust passes out through the space between the two ends of the main piston.

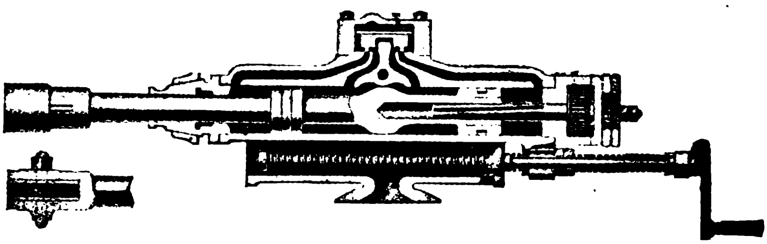


FIG. 62.—Holman Tappet Drill.

All parts of this machine are made to standard gauges, as in fact are all Holman machines; the correct fitting of duplicate parts is therefore assured, while the valve chest can easily be removed should refacing be required. This drill has been in use many years, and given great satisfaction; the air drill, though equally satisfactory, being a more recent introduction.

Fig. 63 shows the general arrangement and valve gear of the Ingersoll-

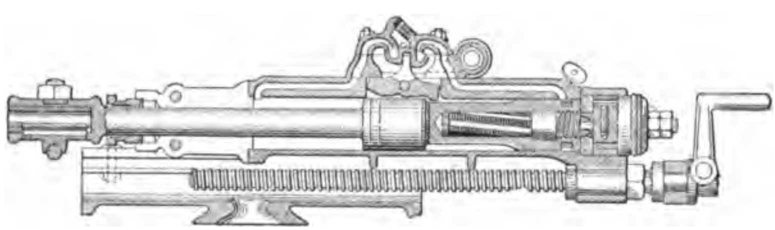


FIG. 63.—Section of Sergeant "Arc Valve" Tappet Drill.

Sergeant arc valve drill; the valve works over an arc of a circle in the direction in which it is impelled by the rocker. The piston is made with sloping shoulders which slide under the rocker, lifting it in the same direction as the piston itself is moving; the valve is held against the face by a coiled spring. In all the machines made by this company the twist gear is the reverse of English practice, the ratchet wheel being a fixture, and the ratchets carried by the twist bar. The piston is a forging of

highest grade steel, rough turned, hardened, and ground true on dead centres, while the cylinders are cast from hard, close-grained iron. So hard are these surfaces that long use serves but to polish the working faces. As all parts are made to limit gauge and template, they are strictly interchangeable.

Fig. 64 is the Ingersoll-Sergeant auxiliary valve drill; it belongs to the third class, the valve motion being a combination of the tappet and air piston. The auxiliary valve is the small curved piece on the right of the

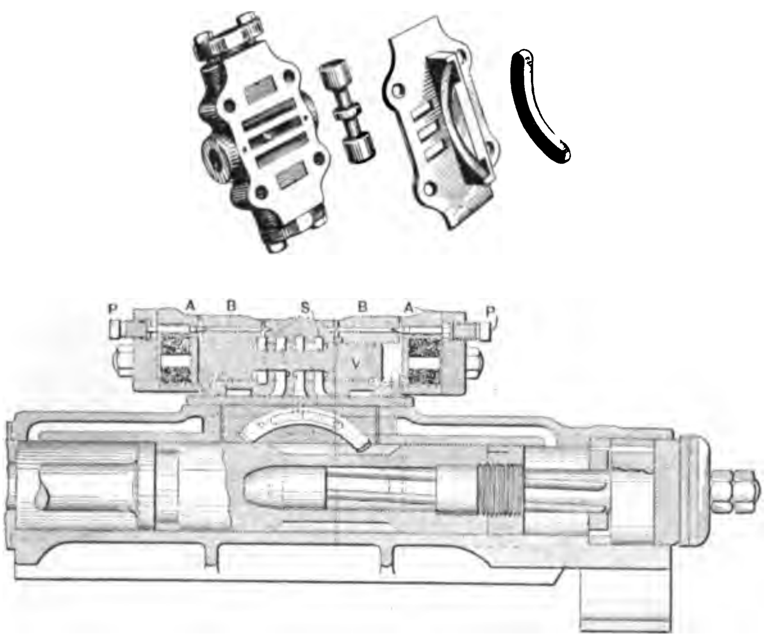


FIG 64.—Ingersoll-Sergeant Auxiliary Valve Drill, and Valve Gear.

valve gear; being rocked in the arc of a circle by the main piston, it acts as a trigger, and admits air to work the piston valve. The small screws P P serve to adjust the stroke should it lengthen after years of work, owing to wear of the piston valve. This machine strikes the dead, uncushioned blow usually made when an intermediate action exists between the main piston and the valve movement.

The following table gives particulars of the drills referred to; the air consumption column is not based on tests, and is quoted as approximate only, being an indication of the size of compressor required :—

Description.	Cylinder Bore.	Stroke.	Feed.	Weight.	Air in Cubic Feet per Minute at 80 lbs. per Square Inch.
	Inches.	Inches.	Inches.	Lbs.	
Holman	2½	5	...	128	47
Ingersoll-Sergeant auxiliary valve	2½	6	20	165	70
Ingersoll-Sergeant arc valve	2½	6	20	190	70
Holman	3	6½	...	190	81
Ingersoll-Sergeant auxiliary valve	3	6½	24	265	100
Ingersoll-Sergeant arc valve	3⅛	6⅝	24	285	110
Holman	3¼	7	...	238	92
Ingersoll-Sergeant auxiliary valve	3¼	6½	24	280	120
Ingersoll-Sergeant arc valve	3¼	6⅝	24	315	125
Holman	3⅜	7½	...	280	105
Ingersoll-Sergeant auxiliary valve	3½	7	24	400	130
Ingersoll-Sergeant arc valve	3⅝	7¼	24	390	140

Mounts.—When used for sinking, the drill and its clamp are mounted on a column consisting of a wrought-iron tube, from 4 to 4½ in. in diameter, furnished with a claw at one end and a tightening screw at the other. Columns of various lengths are required to suit workings of different width. When closed, they are 1 ft. or 15 in. shorter than the distance they are required to span; this deficiency is made up by wood blocking at each end, so that when tightened up, only a few inches of screw project.

In driving, the machine is seldom fixed directly to the column, as a larger area of the working face can be covered at one setting when it is supported on an arm projecting from the column. The single screw fastening is not sufficiently rigid for this method of holding the machine, and the double screw column, as shown in Fig. 65, is generally used. The tripod lacks rigidity and is seldom employed, nor do drill carriages find any favour, as they cannot reach the face and enable work to be resumed until the debris from the former blast has been cleared away.

Upon an upright column the machine can be adjusted to horizontal angles by moving the clamp, and to vertical angles by movement upon the clamp; by combining these movements holes can be drilled at any angle the radius of the support and width of heading allow.

Bits.—As the usual depth bored does not exceed 6 ft., from four to six bits are required for each hole, and constitute a "set." The difference in length in these bits should be about the average depth bored by one; as the length increases, the width of the cutting edge diminishes. An average set would be somewhat as follows:—The starters, made of 1½-in. octagonal steel, about 18 in. in length, and 2 in. wide on the cutting

edge; the length decreases as the bit wears, and starters of various lengths, less than 18 in., will be in use. The second in the set will be 2 ft. 9 in. long, and $1\frac{3}{4}$ in. on the cutting edge; made of the same size steel, so that when worn short they may be used as starters. The remaining bits are

FIG. 65.—Double-screw Column with Drill mounted on Arm.

of $1\frac{1}{8}$-in. steel, the third in the set being 4 ft. long by $1\frac{1}{2}$ in. wide, the fourth 5 ft. 6 in. long by $1\frac{1}{4}$ in. wide, and the last 7 ft. long by $1\frac{1}{8}$ in. wide.

As the result of wear and sharpening, bits in all sorts of intermediate

lengths will be in use. New sets are sometimes supplied in which the bits differ in length by the amount the machine may be fed forward; this has really nothing to do with the case, unless the softness of the ground permits each bit to bore the full feed of the machine. Suppose a bit $1\frac{1}{2}$ in. wide has bored a depth of 1 ft. and then begins to stick, it cannot be followed by another bit of the same width, for if the worn bit stuck, the new one would be still tighter in the hole. The next size, therefore, has to be used, and should it be the full feed length of the machine longer than the former drill, it cannot be placed in the machine for want of room. It is clear, then, that the ground rather than the machine determines the difference in length of the bits.

The number required for each machine also varies with the hardness of the ground, and the work done; thirty each shift would be an average supply, and, as an equal number are being sharpened, sixty bits would be the full complement. When the sharpening is done by hand, the longer sizes are chisel shaped at the cutting edge; the starters should, when possible, be cross bits, as they make a cleaner start than the chisel shape, and are less liable to glance when the axis of the bit is not exactly square with the face of the rock.

Although the shanks may be forged in special swages, it is advisable to have them turned in a lathe. In any case the cutting edge of the bit must revolve truly when rotated with the piston; the clearance between the edges of the bit and the hole is very small, and should the bit be even an eighth of an inch out of truth, considerable friction will result. This will be evinced in the decreased efficiency of the machine for the time being, and rapid wear on the cutting edge; no bit can keep its gauge under such conditions.

Drill Running.—Although the machine drill effects a great amount of work in a given time, it must be admitted the converse is also true, and a little loss of time means much lost work. If the speed in hand drilling be 1 in. in five minutes, a delay of ten minutes means a loss of 2 in. in depth; while with a machine drill boring at 2 in. a minute, 20 in. would be lost in the same time. As a rule the actual boring is done rapidly enough, it is in setting up the column, adjusting the machine to the angle required, and starting the hole that time is occupied.

The experienced runner avoids unnecessary setting by placing his column in a position covering the largest possible area of working face; he inclines his holes and adjusts his charges so that the cut is taken cleanly out, leaving the face perfectly square; he uses his head as well as the machine.

The time taken in setting up would suffice for 10 ft. of drilling; but still greater is the delay when a ragged and uneven face is left after blasting. At least two settings will then be required, as some parts of

the face will be too near, and others too far, from any position the machine can occupy. Worse again is it to have to return over ground already finished and set up just for the sake of a few "pops" in ragged projecting ends of rock.

The unexpected may always happen, and the runner be deceived in the burden on his holes; but this should be the exception, not the rule, with any competent man who has had time to accustom himself to the rock he is dealing with.

The actual position of the column depends largely on the cleavage of the country. In driving across strata the rock may be found to break best towards the hanging wall; the column will then be set towards the footwall side in order to obtain the proper angle on the cutting-in holes. A machine heading is usually carried wider than one driven by hand, otherwise the length of machine and bit prevent a favourable breaking angle for the holes; with a working width of 6 ft. or more, the first cut may be taken from the centre. The column may now be placed about the middle of the drive, and the cutting and squaring holes completed on one side, before the arm is turned round to command the other. In sinking even a small shaft two settings are necessary, the column being placed about 2 or 2½ ft. from the ends.

In each case the length of the column, when the screw is right in, should be 1 ft. or 15 in. less than the width of the working; the wood packing placed at each end absorbs vibration and affords a firm hold on the ground. When the bar has been properly and firmly fixed, and the hole well started, the rest is comparatively plain sailing.

After the machine has been fixed in the required position, the face of the rock where the bit will strike should be trimmed square with the longitudinal axis of the drill—a few blows with hammer and gad are sufficient; but if this precaution is neglected, glancing blows will cause deflection at the very commencement of the hole, and possibly broken shanks and a disabled machine will be the result.

The hose connection is generally of four-ply canvas, armoured with netted or twisted marline, the latter being more easily repaired than the more complicated forms. Air should be blown through the hose to clean it, and the machine oiled before connecting it. It should be possible to lubricate the drill without removing the hose; and one teaspoonful of oil before each hole will be found to answer the purpose better than a cupful at the beginning of each shift.

A starting bit is now fixed in the chuck, and the machine fed down until the stroke is about 3 in., the air cock slightly opened and the machine allowed to run easily, gradually increasing the air supply until a fair stroke may be given without drawing the cutting edge from the hole.

The stroke may now be lengthened and the air supply increased; the machine is fed forward as the hole deepens, the runner being careful to

allow the longest possible working stroke without hitting the front cover of the machine. When the starting bit has reached its full depth, or is blunted and ceases to cut freely, or has lost its gauge and sticks, it is changed for the bit a size longer. The machine itself does not stick, it is always the bit that is at fault, and a tap on the steel will free it; persistent sticking indicates a deflected hole or a bit that has lost its

FIG. 66.—Rock Drill with Spray Attachment for Laying Dust.

clearance and gauge. If changing to a smaller size bit does not rectify matters, it seldom pays to waste further time on the hole. Each time a fresh bit is used, allow it to square up the end of the hole before turning the air full on.

In horizontal holes and those pointing downward, water is fed as soon as a fair start has been made, and assists in keeping the hole clean and

bit cool; the supply may be sufficient to make a thin, liquid mud, or only to lay the dust, between these extremes a point is reached when a thick sticky compound results. This should be avoided, and water applied either as a spray to lay the dust, or in sufficient quantity to wash out the hole. When all the holes have been bored that can be reached from the first position of the column, it is fixed in a new place, or the arm swung round to enable a fresh set of holes to be bored, with inclination opposite to the first.

When the round is completed, machine and column are taken down and carried to a safe distance from the blasting, the machine being covered over as a protection from dirt. As the larger sizes make 300 and the smaller up to 600 blows a minute, and the motive power is comparatively small, good work cannot be done by a dirty, stiffly running machine, nor when the bit is not perfectly free to move without rubbing and reaming the sides of the bore hole.

Maintenance.—On every mine where drills are extensively used, a fitting shop, or a large section of one, will be set aside for their upkeep and maintenance. It will be found a good plan to have each machine brought up once a month, that it may be thoroughly cleaned and wear taken up before it increases. Most of the wear, especially on exposed parts such as the feed screw and nut, is due to the mixture of grit and grease in which these parts work; unless this is cleaned off at frequent intervals, both the life and efficiency of the machine are impaired. The simplest plan, and one saving considerable labour, is to place the dismantled parts in a tank of soda solution, kept at boiling point by a steam jet, or other means.

In most machines the cradle is so easily adjusted to the cylinder that it may be done by the runner while drilling; it is important that these two parts shall be a sliding fit and yet be without shake or play in any direction. Another point equally easily adjusted is at the shoulder of the feed screw and the cradle bracket; many means have been devised for taking up the wear between feed screw and nut, but none have stood the test of continued usage, the alternative is to make these nuts of some simple design, so that they may be cheaply produced and renewed without much expense.

At intervals varying with the amount of work done and care bestowed on the machine, the piston and ratchet springs require renewal, so too do the piston rings; new chuck bushings will be required—when worn they fail to hold the shank of the bit concentrically with the piston. Drills will wear, but should not break or get out of adjustment, and with so many good makes to choose from, there is no place but the scrap heap for those seen every week in the repair shop. Many of the minor repairs are owing to the unnecessary force with which drillers tighten up the nuts

and screws; in tightening two metal surfaces together there is nothing to "give," or yield, and stripped threads are the result.

A lathe is an almost indispensable tool and should be large enough to rebore a cylinder or turn a piston rod; on many mines repairs are carried to the extent of rebuilding worn machines and even constructing new ones. In case of emergency twist nuts may be cast on a twist bar, by coating the bar well with thick whitewash, and warming it before pouring the brass around it. The facilities to be provided for such work will be decided by the cost of imported supplies as against local labour.

Electric and other Drills.—Although the percussive air drill is practically the only one used in gold-mining, rock may also be perforated by other means, and electricity, petrol, or water replace air as the motive power. The boring may be done in three ways—(1) by a percussive action derived from a reciprocating motion, (2) by percussive action from a rotary motion, and (3) by a rotary motion from a rotary motor.

In the last class the rotating bit usually takes the form of an auger or twist drill, and has given good results in the softer measures, such as coal and some ironstones. A machine of this description, working in an iron mine, bored ninety holes of an average depth of 4 ft. in a shift of eight hours, power being supplied through a length of flexible shafting from an electric motor developing 4 H.P. If such results could be guaranteed in gold-mines, the air drill might be sought for in museums.

When the rotating steel bit is applied to hard rock the feed pressure increases and the rate of rotation decreases; this may be noticed in the Calyx machine and in the Brandt drill, so extensively used in the Simplon Tunnel. As far as its action is concerned, the latter machine somewhat resembles a diamond drill without the diamonds, the drilling bits being hollow and furnished with teeth at the cutting edge. The bit is rotated eight times a minute by hydraulic power, and fed forward by a pressure of 10 tons, a constant flow of water being maintained through the tube. The trepanlike teeth seem to crush, rather than cut, the rock; the average rate of boring is 12 ft. an hour in hard gneiss, each drill requiring from 5 to 6 H.P.

The weight of the supports necessary to resist the heavy feed pressure would prevent this class of machine from being applied to ordinary mining work.

In the drill with percussive action derived from a rotary motion, our old friend the hand-power machine turns up in a new guise, and has enlisted both electricity and petrol to do the work for which the human frame is ill adapted. Petrol is evidently unsuited for use underground, both on account of the heat evolved and the fact that the exhaust would need piping to surface. It still remains to be proved whether electric machines can be made both portable and reliable; perhaps managers would not be

so conservative in testing new ideas if inventors were less prone to perfecting them at other people's expense.

Reciprocating Electric Drills exist in several forms—the Edison, Sandycroft-Marvin, Van Depoele, and others; they are much alike in appearance and action, having the cradle, ratchet gear, and feed motion of the ordinary air drill. The bit is attached to a piston attracted to alternate

FIG. 67.—Sandycroft-Marvin Electric Drill.

ends of the cylinder by solenoid coils under the influence of an alternating current. Since the strokes of the drill are synchronal with the alternations of the current, their number in a given time is fixed, or can only be altered by varying the pulsations of the current; but the length of the stroke is capable of wide and instant alteration.

At the rear of the cylinder and in front of the ratchet wheel, a coiled spring is placed, which acts as a buffer and assists the starting of the piston on its forward stroke.

One trouble common to drills of this type lies in the heating caused by rapid reversals of the current; this means loss of power and effect, possible damage to insulation, and in any case additional heat can be dispensed with in most gold-mines.

The working parts are well protected and the actual wear light, the conductors being the parts most likely to suffer from dampness; on the other hand, the machine is heavier and does not bore as quickly as an air drill. The weight varies from 400 to 450 lbs., the feed length is generally 24 in., strokes from 300 to 600 a minute, voltage varying from 110 to 220, H.P. required from three to eight.

Boring Bits.—The compressor may compress and the rock drill pound to no purpose if the bit fails to keep its edge and its gauge, and it will be advisable to consider in somewhat greater detail these important tools and the treatment they receive. This is the more necessary as the duty of keeping them in order falls on smiths, who may, from want of experience or lack of instruction, be led to adopt the shapes and patterns common to hand drilling.

Each individual bit must be correctly shaped and tempered, and the first step towards uniformity in temper is the adoption of one brand of steel for use throughout the mine; it is impossible for any sharpener to obtain uniform results when several brands of different quality are daily passing through his hands.

In selecting a steel, the best will generally be found the cheapest in the end, and although it may not seem advisable to place steel worth £50 or £60 a ton in the hands of inexperienced men, even then it is better to educate them to the care required in handling a high grade steel, rather than adopt an inferior quality.

The welding steels have special advantages in mining work, they are not ruined by a little extra heat, worn-out bits can be joined together, even scraps come handy for steeling picks and other work which the smithy may fall back on in case of temporary slackness.

Although made from one brand, the bits will not be all from the same size stock; it would require too much upsetting to make 1¾-in. bit from a 1-in. bar, and the grain of the metal would suffer in the process. The starters and followers may be of 1½-in. steel, the intermediate lengths of 1¼ in., and the longest formed from 1⅛ or 1-in. bars; the ⅞-in. steel used in hand drilling is crippled by any machine with a cylinder over 2½ in. in diameter. The depth bored by each bit will vary from 8 to 18 in., according to the hardness of the ground, and the difference in length between successive bits will be 12 or 15 in. The difference in gauge is determined in the same way, in hard ground it may be ¼ in., while in soft, ⅛ in. is sufficient; the longest bit is usually 1⅛ in. wide, ensuring an easy fit for the dynamite cartridge. As the diameter of the hole may be

increased with very little loss of speed, it is questionable whether this might not be done, with the advantage of compressing the charge and obtaining concentrated effect at the end of the hole, where it is most required.

The best form for all round work is the plain cross bit; a little extra care is necessary in sharpening it, but each should do at least half again as much work as a chisel bit.

This is evident when we consider that the amount of rock to be removed in each hole increases towards the circumference, and in the chisel bit no provision is made for this extra work. In this bit, too, the maintenance of gauge depends entirely on the two extreme corners. The cross bit may be considered as two chisel bits at right angles to each other,

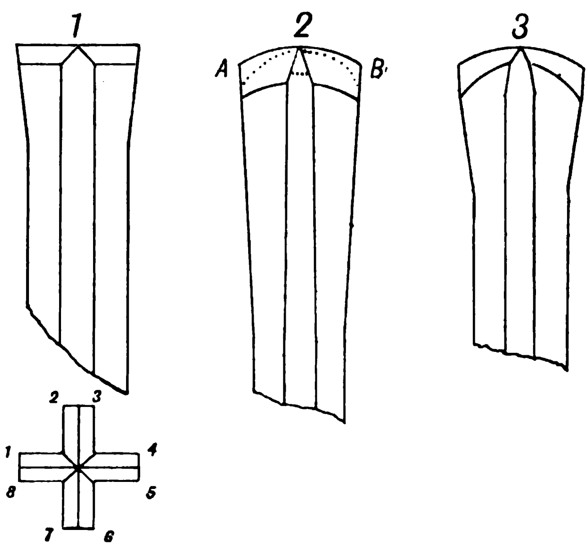


FIG. 68.—Drill Bits.

and presents twice as much cutting edge and has twice as much metal to wear away before the gauge is diminished.

The edges of the cross bit should be perfectly flat on their cutting faces; the rounded or "cock's comb" shape common in hand drills does not keep its gauge, glances from the rock unless the blow is delivered perpendicularly to the face receiving it, and is easily deflected when passing obliquely through strata of varying hardness.

The slope of each lip towards the cutting edge will be 40° to 45°, depending on the hardness of the rock, making the total angle 80° or 90°; it is better to have a comparatively obtuse angle which will be retained, rather than a more acute angle which loses all sharpness in the first dozen blows.

Such a bit, for instance, as No. 2 in Fig. 68, copied from a standard work on mining, and purporting to be a typical bit, would be useless both in hard and soft ground, as it could not keep its edge in one, and would stick in the other. Another serious objection to this form is, the gauge depends on the wear of four corners which have been thinned and weakened until little metal remains, as may be seen in the edge at right angles to A B, No. 2.

Bit No. 3 is the result of careless sharpening. Instead of upsetting and strengthening the whole face, the smith has drawn out, thinned, and weakened each rib of the cross; such a bit possesses in a modified degree all the bad features of No. 2.

No. 1 shows a well-made bit, and attention is particularly drawn to the plan, where each rib is seen to lie flat on its outer face, leaving eight massive corners to ream the hole and maintain the gauge of the bit. Many an otherwise good drill is spoiled in this respect, and sharpeners seem to think the outer surfaces of the ribs should be rounded because the bit works in a round hole. The clearance in No. 1 might be slightly increased if the cutting edge were wider in proportion to the diameter of the bar. The same shape holds good for chisel bits, the cross rib being wanting in this case. Theoretically the edges of an X shape bit are less likely to strike twice in the same place and rifle the hole, but the advantage is not worth the extra labour in sharpening such shapes.

Where several sharpeners are employed it is advisable to keep each on one size of bit as far as possible; he will then have at hand the particular swages, dies, and gauges required.

Steel is easily injured if carelessly treated in the fire. The chief things to guard against are—too fierce a fire, heating the outside of the bar before the inside; an irregular heat, often due to the blast impinging on the bit; prolonged soaking in the fire; and a fire that is either too small or nearly burned out.

The forging heat varies in different qualities of steel, a full red in some, a yellow red in others; welding steels offer most latitude in this respect. All qualities, however, if heated under proper conditions, may be raised to temperatures which would be injurious if carelessly applied.

Even a well-formed bit will be unsatisfactory if badly tempered; there are several methods of hardening, the degree of hardness imparted to the cutting edge depending principally on the temperature of the steel at the moment it is quenched. There are several good reasons for hardening directly sharpening is finished, known as "plunging off the anvil," but the great objection to the plan is that no particular temperature can be assured at that moment. To secure uniformity, therefore, it is best to reheat the steel, but the heat should be short, the object being to provide a hard cutting edge with a tough backing. Even when care is taken, the length heated is generally in excess of that to be hardened, and if the bit is

cooled, the last $1\frac{1}{2}$ in. at least at the end will be found hard, and more or less brittle. This may, in a measure, be rectified by decreasing the degree of hardness, a process known as tempering. When the hardened bit is again heated, the hardness passes off, not all at once, but gradually, each successive stage of decreasing hardness being recognisable by the colour on the surface of the steel. These colours show up vividly on high grade steels, and faintly on poor qualities; in each case they are easier to discern if the surface of the metal is brightened. On being heated to 440° Fahr. the bit, which was when dead hard of a greyish white colour, begins to tinge with yellow, and the softening process should be stopped by quenching in cold water; the same colour serves also for hammer heads. If the heating is continued to 470° Fahr., the colour will be full yellow, or straw colour; at 490° Fahr. an autumnal shade of yellow brown is seen; both these colours are suitable for metal turning tools. The full brown, or copper colour, at 510° to 520° Fahr., is used for taps, dies, and axes; the purple blue at 540° Fahr. for chisels, cutlasses, and knives; at 600° Fahr. is the full blue spring temperature for saws, and if heated beyond this point the effect of the original hardening is lost.

The temperature to which drill bits should be let down is therefore 440° Fahr.; a degree of heat which can be secured by placing the hardened bits in a molten mixture of one and three-quarter parts lead and one part tin. There is not the slightest doubt that an excellently hardened drill results from this system of tempering, but unless the above hardening bath is used, the time occupied is an objection. The smith has to watch the slowly heating bit for the required shade of colour, and be ready to cool it when that shade is reached. To meet this objection, the following alternative plan is offered, the product is equally uniform, and the author has employed it with great success, having first noticed the idea in Colorado.

The hardening tank is provided with a diaphragm of coarse wire gauze, placed horizontally and supported at frequent intervals to keep it quite level; the cooling water enters near the bottom of the tank, and the overflow is fixed so that the water shall cover the screen to a depth of half an inch. Racks are placed above the tank to hold the drill shanks in a vertical position. The heated bit is simply placed in the tank where it rests on the wire gauze, only the last $\frac{1}{2}$ in. of cutting face being below the water, and is maintained in an upright position by the rack. If a bar of steel 1 in. in diameter were treated in this manner, it would stand a chance of being ringed at the water level; but owing to the thinness of the ribs this will not occur to the bit, provided it is not overheated. The thin tumbler stands boiling water, while the thick one cracks; the heated end of the bit is in contact with a comparatively small body of water, and the thin ribs conduct the heat and prevent any sudden contraction or "ringing."

The **Diamond Drill** is the modern telescope, enabling the miner to "see beyond the point of his pick," to locate and prove the continuity and extent of ore bodies, and to obtain some idea of their probable richness.

The duty of this machine is to get samples from inaccessible places, and for this purpose it is provided with tubular drill rods armed with a diamond-set crown on the lower end; this rim, or crown, cuts an annular hole, leaving a centre piece, or core, which can be withdrawn, more or less intact, as the sample.

Fig. 69.—Sullivan "E" Drill, mounted on columns for underground work. Capacity, 400 ft.; core, $1\frac{3}{8}$ in. diameter; weight complete, 580 lbs.; weight of heaviest piece, 125 lbs.

In South Africa the machine has been chiefly employed in boring from surface, to prove the underlying reefs, and on its indications large amounts of money have been spent in shaft sinking. There is little doubt much of this deep sinking would have been at all events deferred, but for the information afforded by bore holes.

But the value of the diamond drill as a prospector is by no means confined to surface work, it is equally important underground as a medium for testing the country surrounding existing workings. This is specially the case when ore bodies of patchy values and irregular formation have to be dealt with, and in Colorado, West Australia, and other countries, the drill has largely superseded cross-cutting.

The machine itself contains the mechanism for three separate actions, rotating, feeding, and withdrawing the drill rods; the motive power may be steam, compressed air, or electricity, the motor being supplied with the drill in either case. The pump is usually included in the outfit, leaving only power and water to be supplied.

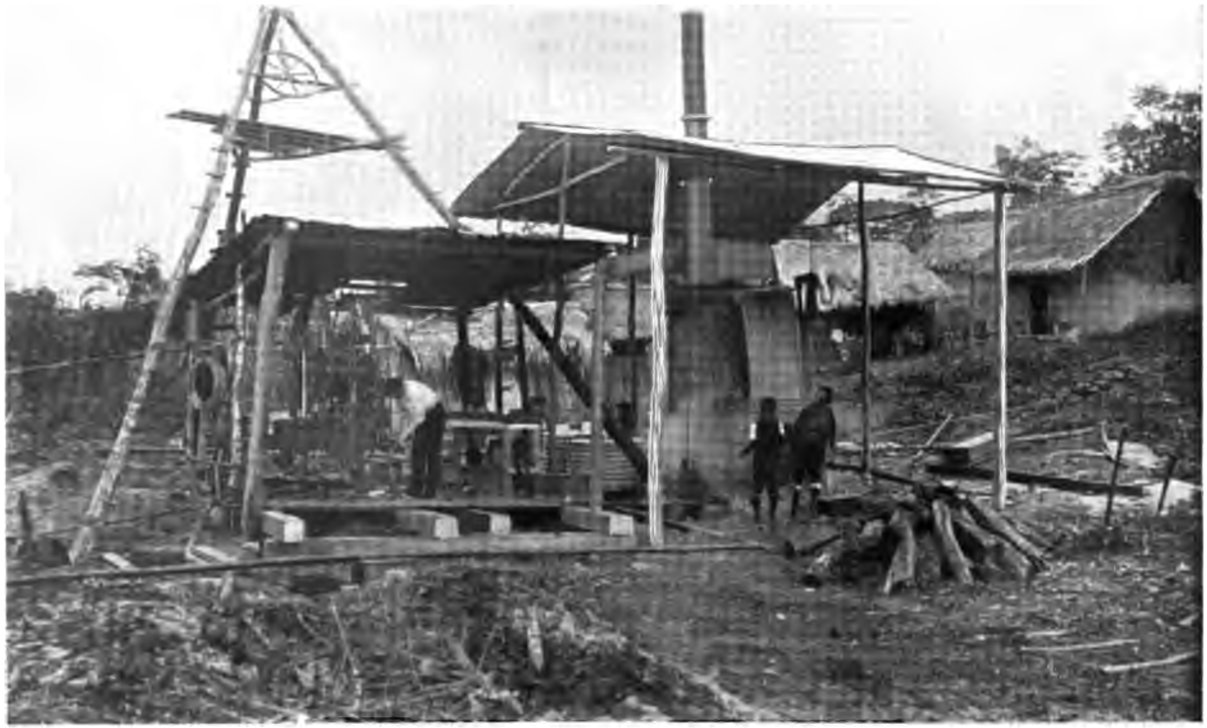


FIG. 70.—Diamond Drill boring a 600-ft. Inclined Hole, West Africa.

[To face p. 172.

Although the description applies to any form of drill, it refers more especially to those made by the Sullivan Manufacturing Company of Chicago, who turn out drills of between twenty and thirty different capacities, and who have themselves carried out many important boring contracts. As the result of having the machines constantly at work under their own supervision, matters of detail and construction have been improved until the diamond drill of to-day is as nearly perfect as the bicycle and typewriter. The Sullivan "E" drill is illustrated in Fig. 69.

The whole machine is mounted on a cast-iron base-plate resting on a wooden frame; it is not rigidly attached to this base-plate, but can be racked back out of the way of the rods when they are being hoisted. The engines are placed vertically, and in all but the smallest sizes have double cylinders; if electricity is used, the motor is wound for 110, 220, or 550 volts, other voltages being arranged for by special winding. The drill rods are always driven through bevel gear, consequently they may be turned in any direction around the central bevel wheel, and holes bored at any required angle. The hydraulic feed gear is particularly neat, and consists of a vertical water cylinder fitted with a piston and hollow rod through which the drill rods pass.

This piston, of course, does not rotate with the rods, but is connected to them by an overhead ball bearing. The cylinder is filled with water both above and below the piston, and no matter how great the pressure above may be, the piston cannot descend until some of the water beneath it is displaced. The entry and exit of the water are adjusted by two valves on each side of the cylinder, and the drill runner can therefore regulate his feed to any required pressure. It will be seen the rate of feed is in no way a fixed quantity, all that is done is to apply to the piston such pressure as the rock requires, leaving the bit free to advance as it cuts.

A gauge on the hydraulic cylinder shows the total feed pressure, and also indicates the resistance opposed to the progress of the bit; while the water under the piston prevents the rods from falling should a cavity be struck—at the most they can only fall an amount equal to any play in the ball thrust bearing. That an unlimited range of feed pressures is required in work of this kind is evident when it is considered that, in addition to any changes in the hardness of the rock, the drill rods are always varying in weight. When the hole is shallow the weight of rods may be insufficient to cause the bit to cut; as the hole deepens and rods are added the amount of pressure required decreases; later on the rods are of more than sufficient weight and some of it must be taken off the crown by the water beneath the hydraulic piston. In some of the smaller drills the hydraulic arrangement is replaced by a differential friction driven feed, the pressure being adjusted by regulating the tension of the spring acting on the friction washers. The rods are held and driven by a clutch, to their upper end is fastened the

water swivel and hose connection, while to their lower end the core barrel, extractor, and crown are attached.

Erection.—The only foundation required is a firm and level platform to carry the machine; this is obtained by four mud cills, each about 8 in. square by 12 or 14 ft. long; they are well bedded, levelled up, and covered with a floor of 2-in. planking. These cills should be so laid that the weight of the drill comes on two of them, not on the flooring. The floor is roofed over, a space being left for the rods to pass through; in cold climates the floor space is housed in as a protection to the men employed. The derrick by which the rods are raised and lowered is now placed over the bore hole; for bores of 500 or 600 ft. in depth, a tripod 35 ft. high is sufficient. As the depth increases a constantly increasing proportion of the time is occupied in raising and lowering the rods, and the shorter the length of rod dealt with at one time the longer the whole operation takes.

In all deep boring the height of the derrick becomes an important factor in determining the rate of progress, and it should permit rod sections 50 ft. in length being disconnected at a time. These high derricks may be built of timber, but if many bores are to be made, the tubular steel structure illustrated in Fig. 72 (p. 177) soon pays for itself; not only is their total weight much less, but the various sections do not greatly exceed 1 cwt. each. They are constructed entirely of stout steel piping held together by steel joint pieces, no screwed threads being used.

Another factor affecting the rate of deep boring even more than the height of the derrick is the length of the core barrel; this, provided the crown stands, determines the depth that can be bored before hoisting the rods, and consequently the number of hoists required in any given increase of depth.

When the necessary water and steam connections have been made to engines and pump, everything is ready to start drilling, provided the rock outcrops. But the surface is usually covered with a considerable depth of earth, sand, gravel, and decomposed rock, which would cave and fill the borehole. These strata are bored through with a chopping bit, worked from the engine by a rope around the hoisting barrel, and the hole lined with pipe; the driving is done by screwing a drive-head on the upper end of the pipe and letting a weight fall on it. The weight is lifted by the engine, the action being similar to that of a pile driver.

Even when these upper strata are passed through, there may still be several feet of broken rock, pieces of which might fall into the bore; this is bored through with a large crown and lined with casing pipe dropped inside the drive pipe.

When this casing is firmly jointed to the solid rock the usual routine of boring commences, the diamond-set crown cuts its annular hole, leaving the core standing within the tube or core barrel. The core lifter lies within

the barrel and is free to slide down over the core but cannot be pulled up over it; when the bore has reached such a depth that the core barrel is full (5 or 10 ft.), drilling is suspended and the rods lifted. On the first upward movement of the rods the core lifter seizes and detaches the core, retaining it within the barrel until it is brought to surface. In deep work core barrels of greater length are used, 15 and 20 ft. lengths being employed, provided the crowns can cut to that depth at one setting.

A constant stream of water is pumped down through the rods, and passing underneath the crown, returns to surface outside the rods, bringing with it the sludge and borings made by the bit; this water may be settled in tanks and used again.

Provided the water returns to surface, a daily supply of 2,000 gals. will be sufficient; but the bore may at any time strike a crack or fissure in the rock into which all the water passes, none returning to the mouth of the borehole. This contingency should be guarded against by providing a full supply of 3,000 gals. daily.

The bort, or carbons, are usually in pieces from 2 to 3 carats in weight, the larger sizes being preferred, as the weight is constantly being reduced by wear. The stones should have no decided and prominent angles, as in cut brilliants or fragments of hardened steel; rounded, obtuse angles are better, as affording more support to the cutting point.

The crown is formed of soft charcoal or Swedish iron, set with eight to sixteen stones according to the size of the bore; at least two of the stones are set to give clearance on the inside, and two others on the outside of the crown, the remainder being disposed so as to cover the cutting face. The clearing stones should project about $\frac{1}{32}$ in. from the crown, cutting a clearance space of $\frac{1}{16}$ in. around the rods.

When setting the crown, the seatings are marked off and bored out with a hand drill, the bored holes being afterwards enlarged to fit the stones; when each stone has been well seated, it is fixed in position by caulking the soft iron securely round it. In rock of average hardness, a well-set crown will bore from 12 to 18 in. an hour; but no correct estimate of speed or cost can be given, as the conditions vary not only in different districts, but hourly in each borehole.

The average of sixty bores in metamorphic rock, made in Australia, South Africa, and West Africa, is a daily rate of 20 ft., the bores averaging 570 ft. in depth. The cost of such work is between 15s. and 25s. a foot. In bores more than 1,000 ft. in depth the speed falls off, and the cost increases to 25s. or 35s. a foot; these figures do not cover depreciation on plant, nor contractor's profit, when the work is done on the contract plan. The wear of carbons works out exactly at 10s. a foot over the sixty bores. The cost may be increased by mishaps, such as meeting with broken ground, when loose fragments tear one or more carbons from their seatings; these loose carbons speedily destroy the rest of the crown, and

drilling is suspended until they are recovered by embedding them in a lead bit.

Theoretically the bore should be perfectly straight, but the long line of light rods is easily deflected by oblique strata. The amount of deflection

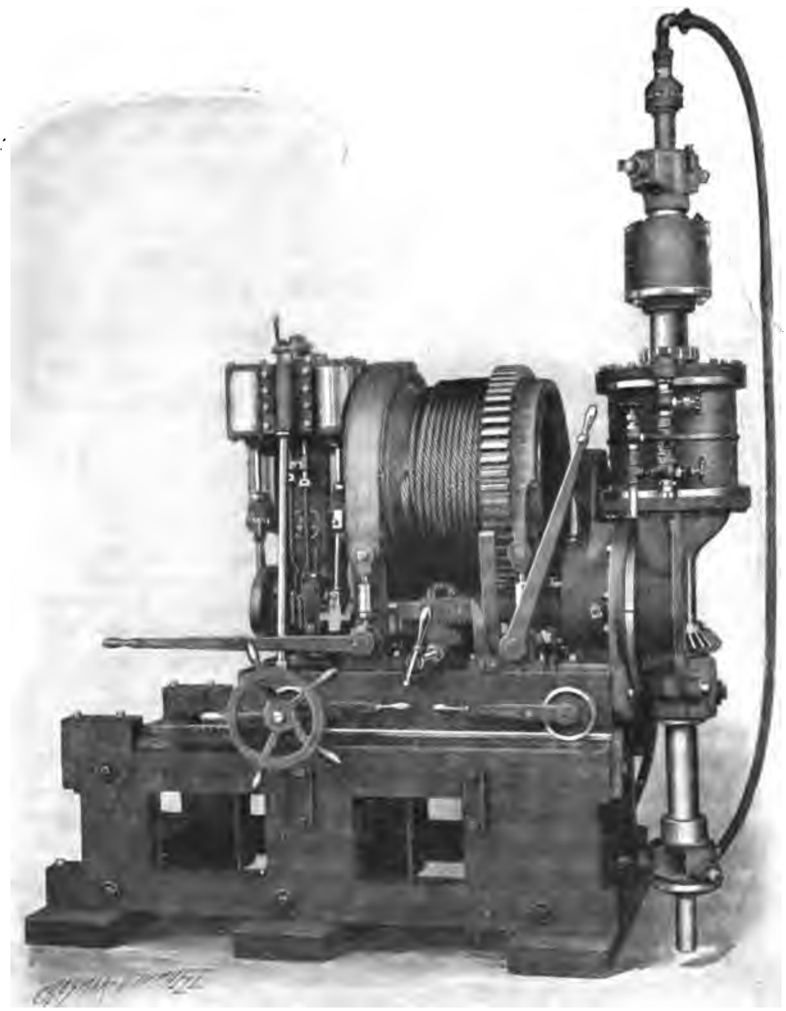


FIG. 71.—Sullivan "P" Drill, suitable for a depth of 4,000 ft., core 2 in. diameter. The general arrangement of the parts is very clearly shown. The engine is on the left, the hoisting drum in the centre; the hydraulic cylinder is on the right, surmounted by the ball thrust bearing communicating with the drill rods; the chuck holding the rods is shown at the bottom of the hose pipes.

is roughly ascertained by magnetic and dip needles immersed in warm gelatine solution which solidifies in the borehole; the position assumed by the needle with regard to the glass tube in which it is set gives an approximate idea of the deviation.

The machine shown in Fig. 71 is one of the most powerful made by the Sullivan Company, and has put down some of the deepest bores in the South African gold field, a country in which an unusual number of deep bores have been made in order to locate the reef at increasing distances from the outcrop. The deep bore at Doornkloof was carried to a depth of 3,200 ft. by the Sullivan "N" drill, which has a rated capacity of only 2,000 ft., and was completed at 5,560 ft. by the "P" drill, with a rated capacity of 4,000 ft. It will be noticed that the Sullivan machines are rated well within their capacities. When the bore was nearing completion the rods alone weighed between 15 and 16 tons, this weight being handled by the engine without difficulty. The boring occupied fourteen months, an average speed of 400 ft. a month; the rods were pulled in 50 ft. lengths by means of a tubular steel derrick 66 ft. high. At a depth of 5,000 ft., $3\frac{1}{2}$ hours were taken in lowering the rods, and from $3\frac{1}{2}$ to 4 hours in hoisting them.

FIG. 72.—Patent Tubular Steel Derrick, made in sections for transport.

It was the "P" drill also that bored to 5,582 ft. at Springs, near Johannesburg, beginning on 1st May 1904 and finishing on 2nd February 1905, an average speed of more than 600 ft. a month for over a mile in depth.

Particulars of Sullivan Diamond Drills.

Size of Drill.	Depth of Hole.	Diameter of Core.	Motive Power.	Boiler.	Size of Pump.	Weight, including Equipment, Lbs. Packed.
	Feet.	Inches.		H.P.		
M	300	$\frac{15}{16}$	Hand.	...	...	1,351
E	400	$\frac{15}{16}$	Steam or air.	8	$4\frac{1}{2} \times 2\frac{3}{4} \times 4$	2,034
S	500	$\frac{15}{16}$	,, ,,	8	$4\frac{1}{2} \times 2\frac{3}{4} \times 4$	2,606
H	1,000	$1\frac{1}{8}$	,, ,,	10	$4\frac{1}{2} \times 2\frac{3}{4} \times 4$	3,997
HG	1,000	$1\frac{1}{8}$	,, ,,	10	$4\frac{1}{2} \times 2\frac{3}{4} \times 4$	3,997
C	1,500	$1\frac{1}{8}$	,, ,,	12	$6 \times 4 \times 6$	4,556
B	3,000	$1\frac{3}{8}$	,, ,,	15	$6 \times 4 \times 6$	6,035
N	2,000	2	,, ,,	20	$7\frac{1}{2} \times 4\frac{1}{2} \times 6$	6,703
BN	500	2	,, ,,	10	$6 \times 4 \times 6$	5,721
CN	800	2	,, ,,	10	$6 \times 4 \times 6$	5,721
P	4,000	2	,, ,,	25	$7\frac{1}{2} \times 4\frac{1}{2} \times 10$	10,794
PK	5,000	$1\frac{3}{8}$	,, ,,	30	$8 \times 4 \times 12$	19,920
K	6,000	2	,, ,,	40	$8 \times 4 \times 12$	40,920
R	300	$\frac{15}{16}$	Electric.	...	$6 \times 4 \times 6$	3,186
RS	500	$\frac{15}{16}$	,,	...	Triplex electric.	6,294
RH	1,000	$1\frac{1}{8}$	,,	...	,, ,,	4,797

Particulars of Derricks (pp. 174, 177).

Height.	No. of Legs.	Will Hoist	Safe Working Load.	Weight of Derrick.
Feet.		Feet.	Lbs.	Lbs.
30	3	24	4,000	1,500
38	3	32	5,000	1,900
38	3	32	10,000	2,300
52	3	45	15,000	4,100
63	3	55	20,000	5,400
52	4	45	18,000	5,500
63	4	55	24,000	7,000
77	4	67	40,000	20,000

CHAPTER XI.

CRUSHING MACHINERY.

Stamp Mills—Selection of Site—Mortar Boxes—Foundation Piles—Screens—Cams—Framework—Guides—Stamps—Speed—Order of Drop—Duty—Erection—Amalgamating Tables—Water Supply—Ore Feeders—Rock Breakers—Steam, Pneumatic, and Spring Stamps—Grinding—Pans—Settlers—Ball Mills—Tube Mills—Rolls.

Stamp Mills.

WITH the possible exception of the amalgamating machine, in which the pulp is to strain through a mass of quicksilver, no part of mining equipment has received so much attention from the inventor as the stamp mill. There are, or have been, one-head stamps, spring stamps, steam stamps, pneumatic stamps; batteries have been made with two cam shafts, one to knock the stamp down, the other to lift it up; and the blow given by the revolving stamp has been increased by coiled springs and air cushions. Yet the fact remains that the revolving stamp, in practically the same form as it was a quarter of a century ago, is universally employed for reducing simple ores.

Improvements have been made within the period mentioned, but they affect neither the shape, form, nor action of the machine; the weight of each head has been increased, the single arm cam has disappeared, ten of them are no longer seen on a shaft, the gear drive and double discharge mortar have practically gone; but the trifling nature of these modifications is perhaps the best testimony to the stamp's suitability to its work.

The strong point of the stamp battery is that it consists of a few simple parts, those liable to wear being easily renewable; and the efficiency of the machine cannot be increased by any additional parts without detracting from this simplicity.

There is certainly no part of the whole equipment of the mine requiring more careful location than the mill, and it may be that a difference of a few hundred feet in the position of the site will materially affect the cost of the process.

The requirements of a good site are—(1) sufficient fall to ensure an automatic process and room for disposal of tailings; (2) accessibility for ore, fuel, and water supplies; (3) firm ground, to afford a solid foundation.

The fall is of such importance that other considerations are often sacrificed to secure it; if it be insufficient, either the pulp or the tailings must be handled before the process is completed, and the cost of treatment thereby increased. When once the ore is loaded into trucks or skips, the cost of tramming it a little farther or hoisting a little higher is immaterial, but a separate handling is quite another matter, entailing expense which may be avoidable. In an ordinary mill, fitted with concentrators, pans, and settlers, 35 ft. is the minimum fall permitting an automatic process; 40 ft. is better still, while 70 ft. will be required if the cyanide process is added. It is not necessary that the mill site should slope to this extent, as height may be gained by delivering the ore at some distance above the ground level; but no opportunity of increasing this fall should be neglected, to provide for the disposal of tailings below the mill.

Although the weight of water required at the mill exceeds by six to nine times that of the ore treated, yet, as the former is easily and cheaply handled and is delivered at a lower level, the ore supply becomes the chief consideration. Here the distance from the shaft becomes a factor, the ideal conditions being attained when ore can be delivered from the shaft to the battery bins by belt conveyors. In every case, if the ore supply is well carried out, neither the fuel nor the water are likely to cause difficulty.

The firmness of the ground is of secondary importance, as in bad footings the mortar piles may be extended in depth, until their own dead weight and the side pressure of the ground relieve the bottom from the force of the stamp blow. Made or filled ground should be avoided, neither should the mill stand on the back of the reef, where the foundations may be undermined by stoping at shallow levels.

The area required will be considerably more than that of the building, as room will be required for storage of fuel, water, and possibly for ore, settling tanks, and tailings. In laying out the ground nothing of a permanent nature should be allowed to occupy space which may be needed for extension of the plant, even though such extensions are not contemplated at the time.

Each stamp battery consists of four main parts: the mortar box and foundation it rests on, the cam shaft and cams, the framework supporting the cam shaft, and the five stamps.

Mortars.—The duty of the mortar is to provide a firm bed for the dies, to hold the screens, and to retain the pump until of sufficient fineness to pass through the screens. Mortars which are narrow in width increase the rate of discharge by bringing the screen nearer the stamps, so that the pulp is not only washed, but to some extent driven, through the perforations. This cannot be done without exposing the screen to greater risk of injury.

The rate of discharge is also affected by the distance from the top of the die to the bottom of the screen; the closer these are together the more the blow of the stamp tends to drive the pulp through, and also to injure the screen by flying fragments of stone. As this distance increases with the wear of the die, mortars are sometimes provided with loose false bottoms, on which the half-worn dies can be packed up.

Amalgamating plates were formerly fitted inside the mortar, and are still used where the ore contains coarse gold; but the modern tendency is to use the stamp battery more as a crushing machine, and to make the gold extraction a separate process. The lower part of the mortar, exposed to wear by the friction of the pulp, is usually lined with steel plates about an inch thick, each set lasting a year on the average.

Mortars can be sectionalised for convenience in transport, and the bottom part built of several pieces with machined faces, held together by longitudinal bolts turned to a driving fit into reamed holes. The upper part, or housing, is made of boiler plate. A difficulty is found in securing the upper and lower parts together, since neither bolts nor rivets will stand the vibration. The only plan that has proved satisfactory is to provide a dove-tailed groove 2½ in. deep around the bottom, to drop the housing into this groove, and secure it by a caulked rust joint.

The foundation piles or blocks on which the mortars rest are generally composed of eight timbers, bound together at the top and bottom so as to form a block about 27 in. from front to rear, and 5 ft. if measured in the direction of the cam shaft. The length must be such as to allow the lower end of the block to rest either on rock or compact picking ground. In order to avoid side settlement, the depth below ground should always be at least twice the height above the surface. These piles are either supplied with the battery, or obtained locally where timber is abundant.

Screens.—No screens present so large an area of discharge within a given space as those made of woven wire. They are not, however, generally used, as the wires are easily displaced, closing some of the discharge openings and enlarging others.

They are also easily broken; when made of iron or steel they are liable to rust, while brass and copper are unsuitable if mercury is fed to the mortars, as their openings become blocked with amalgam. The life of a wire wove screen is from ten to twelve days, but the life of a screen should not be reckoned in days, rather by the tons of correctly sized pulp it has discharged.

Russian iron or sheet steel is preferred on account of its greater strength; when punched with round holes the gauge is known by the number of the sewing needle fitting the perforation, or by the number of perforations to the square or linear inch. Slotted screens generally have

the number of their gauge stamped on the margin; those of 30, 40, and 50 gauge being commonly used.

When the battery acts as the gold saver, the gauge of screen employed must ensure the fine gold being liberated from the gangue, with a minimum of sliming the pulp and flouring the gold.

As the discharge takes place almost entirely from the lower 6 inches of the screens, they are usually turned upside down at the end of a fortnight; even if not broken by a month's use, the perforations will be enlarged beyond the gauge required.

SCREEN TABLE.

No. of Needle.	Mesh.	Width of Slot.	Weight per Square Foot.
5	20	$\frac{29}{1000}$	1.15
6	25	$\frac{27}{1000}$	1.08
7	30	$\frac{24}{1000}$	0.987
8	35	$\frac{22}{1000}$	0.918
9	40	$\frac{20}{1000}$	0.827
10	50	$\frac{18}{1000}$	0.735
11	55	$\frac{16}{1000}$	0.666
12	60	$\frac{15}{1000}$	0.666

Cams.—The proper curve for the face of the cam is the involute of a circle whose radius is the distance from the centre of the cam shaft to the centre of the stem; the lift of the cam will then be in the centre of the stamp stem, and no pressure thrown on the guides until the toe of the cam has passed the centre line of the stem. The distance between the cam shaft and stem is therefore fixed in the design of the cam, and if it is altered by wear of the guides, or guides of incorrect thickness, the lift will no longer be in the centre, and friction will result.

When the arm of the cam, in the course of its revolution, strikes the tappet, the stamp is not lifted with gradually accelerated velocity, but is moved with almost maximum speed The impact of these two unyielding surfaces causes vibration, and even fracture of the shaft. This danger is increased the farther the point of contact is from the root of the cam; the radial length of the cam arms should not therefore be longer than the lift requires; that is to say, a cam designed for a 10-in. lift should not be used for a 7-in. The stamp does not fall immediately the cam has parted from the tappet, in fact at high speed it continues the upward motion imparted to it, until at ninety-five drops a minute a 7-in. drop results from a 6-in. cam lift.

The lift provided for by the cam varies in different localities, lifts of 15 in. and 18 in. being still used in some parts of Colorado and

Australia, and it is claimed that they are necessary for the ore treated. It is generally noticeable that batteries with such excessive drops are seldom provided with stone breakers, and the battery has to deal with a particularly coarse feed. Modern practice tends towards a high speed and short drop.

A spare shaft with cams mounted on it is usually kept ready in every mill. This is more to guard against accident, as the life of a properly lubricated cam is eight to ten years.

As the cams are double armed, every revolution of the shaft causes each stamp to drop twice, or five stamp-drops for each half revolution, and the keyways in the cams must be placed so as to effect this drop in proper order and sequence. When this order of drop has been decided on, each cam is suited to only one position on the shaft. An additional keyway, fitting the cam for another position, may easily be cut by mounting the cam on a spare shaft and drifting out the groove required in the bore; the drift being backed up by an additional thickness of tin or galvanised iron after each cut. Keys may, however, be dispensed with and the cams secured by curved wedges, the cam by its own action tending to fasten itself more firmly on the shaft.

Framework.—The chief parts of the framework are the three battery posts, which support the cam shafts, and are braced together by the guide bearers and guides. Each post rests on a solepiece, in turn supported by four mud cills. When ore bins are fitted, the posts are braced back to them, otherwise they are supported by inclined struts placed at the rear, so as to permit free access to the amalgamating tables. Pitch pine is the timber generally used when the framing is supplied with the mill. Iron framing is no longer employed; it was formerly preferred for countries where white ants are found, but the constant vibration of the framing affords sufficient protection against this pest, and timber may safely be used in such localities.

The Guides.—The upper and lower guides are supported by the bearers connecting the battery posts. As already explained, there should be no pressure on the guides until the toe of the cam has passed the centre line of the tappet, when the lift becomes a radial one. Guides may be made of any tough hardwood. Before the holes in which the stems work are marked off, packing pieces about ½ in. thick are interposed between the two halves of the guides, so that wear may be compensated by reducing the thickness of these strips. It is advisable to overhaul the guides every month, as when once play has developed it readily increases, until heads and shoes are knocked off and stems broken. After the packing strips have been entirely removed, wear can be taken up by dressing down the guide faces, but this must be allowed for by packing

up the back guide, or the distance between shaft and stem will be altered. In a few districts, iron guides lined with white metal are still in use.

The **Stamp**.—The stamp consists of the lifter, tappet, head, and shoe; the total weight of these combined parts was formerly about 850 lbs., but has gradually been increased until a heavy stamp is now between 1,000 and 1,600 lbs. in weight.

The stem, which works in the guides, is parallel throughout except for a length of about 6 in. at each end, where it is turned to a taper of one in twenty, the hole in the head being bored to the same taper.

The tappet is bored to fit the stem, and secured to it by two or three keys acting on a gib. It is very necessary to see that these keyways are so placed that the keys may press on the gib, and not bind in the keyways, merely tending to split the boss of the tappet.

The head is bored to fit the stem, and provided with a drift hole for removing the stem. When once well set, the stem can seldom be detached in this way, and either heat or dynamite is used. The lower part of the head is furnished with a recess which should correspond in taper with the shank of the shoe. If these do not correspond, wedge shaped, instead of parallel, packing strips must be used to secure the shoe. When the shoe is thin, the lower part of the head is worn away by friction of the pulp in the mortar, and is finally split by the tapered shank of the shoe.

Where the cost of transport is considerable, steel shoes and dies are preferred to those made from cast iron. The wear falls chiefly on the shoes and dies, more on the former than on the latter, as the shoe strikes with a clean face, while the die is protected by the pulp.

Speed.—The number of drops a minute depends on the length of drop, and partly on the proportions of the cam. If driven too fast the stamp will be "cammed," or caught again by the second arm before its fall from the first is completed—a danger that is increased by using cams with arms longer than the fall requires.

A rapid drop assists discharge, by keeping the pulp in constant agitation within the mortar, and most mills are now driven from 85 to 95 drops a minute. At the higher rate the lift is limited to 7 in., and is further diminished if the speed is increased; it follows that the effect of each blow would be less, unless weight is added to the stamp. As instances of extremes of practice, mills are running at forty 15-in. drops a minute, while others make from 100 to 105 drops a minute daily.

Order of Drop.—Opinions differ on this point, and there is certainly no specific order that is best under all conditions.

In arranging the stamps to fall in some particular rotation, the object is to secure an even distribution of pulp within the mortar and an even discharge from it; and the results obtained by any particular succession may be modified by altering the position at which ore and water are fed. As a general rule the ore is delivered by the self-feeder to the centre of the mortar, and the task of distribution is thrown primarily on the middle stamp. If the stamps on each side of it are on their dies when the centre one falls, the splash of pulp will be obstructed in each direction; neither of these, therefore, should be the last to fall.

The order, 5, 3, 1, 4, 2, fulfils these conditions and is extensively used, as also are 1, 5, 2, 4, 3, and 1, 4, 2, 5, 3.

If the order in use does not afford an even distribution, it may be improved by feeding the ore or water at a different point, or by giving increased drop to the stamps that get more than their share of pulp. Thus in the order 3, 4, 5, 2, 1, the three heads on the left fall consecutively from left to right, and tend to block up the remaining two; this might be rectified by feeding towards the left of the mortar, or by increasing the drop of 1 and 2.

It is evident, then, that a sequence that has afforded good distribution when the battery was hand fed may no longer give satisfaction if self-feeders are introduced. In hand feeding the stamps can be humoured, in machine work they are supplied only at one point and left to carry out their own distribution.

The Duty.—No millman will agree with the oft-printed statement that the duty or output of the battery depends on the area of discharge; no matter how large the screen surface, it is impossible that every particle of pulp in a body some 5 ft. by 15 in. shall be free to escape directly it is fine enough to pass through the perforations in the screen.

Enlarging the screen area does not substantially increase the rate of discharge, and, experimentally at all events, a mortar with the usual screen surface has been found capable of discharging twice the quantity crushed by any gravitation stamp battery.

When the gold extraction is a separate operation from the crushing, the output of the battery is limited only by its capacity for crushing, but when the operations are combined in one process, the duty of the battery may be limited by the capacity of the amalgamating tables. The term "duty" refers more particularly to the number of tons crushed per stamp in twenty-four hours, and is affected by several factors, which are here given, as nearly as possible, in the order of their importance:—

1. The character of the ore, clayey tenacious ores being the most difficult to treat, friable ores the easiest; a hard ore being more rapidly crushed than one which is tough or ductile.

2. The size and number of the screen perforations.

3. The number of drops per minute
4. The weight of the stamp
5. The height of the drop

$\left.\right\}$ = horse-power employed.

6. The height of the discharge above the dies, and the distance between the screen and the stamp.

7. The quantity of water used per ton of ore.

The output is not increased by reducing the ore to any smaller size than that afforded by a good stone breaker; even when fed with sand and gravel the duty is not increased. The reason seems to be that the blow does not take effect on the projecting angles of a comparatively few pieces of stone, but is cushioned by being received by an even layer of pulp spread over the whole face of the die.

Since the number of drops has not been increased and the screens are the same gauge, it is mainly the additional falling weight that has raised the duty of the modern stamp to from five to seven tons per twenty-four hours, as against two tons crushed by the 850-lb. stamp.

Before describing briefly the erection of a stamp mill, it is well to emphasise the fact that the soul of the mill lies in its foundations, and that its life and total output depend on the care bestowed on this important and hidden part of the work. Repair is impracticable, total re-erection the only remedy for faulty workmanship or bad material.

Erection.—As the site will probably be on sloping ground, the first step will be to grade to the levels of the various floors, working from the height at which the ore is to be delivered as a datum.

The battery floor will be graded to the level of the bottom of the mud cills, and will be subsequently raised a foot or more by filling around these timbers; the concentrator floor will be brought to the right distance beneath the battery level, and the vat floors also graded to their proper height. While this work is in hand it is often advisable to take out enough ground for an additional battery.

The centre line of the mortar blocks, as shown on the general plan, will be laid off on the battery floor and permanently marked by posts set at least 6 ft. distant from the ends of the foundation pit.

These posts should stand above the ground at least as high as the tops of the mortar blocks; when the nails on their tops are not in use they should be covered with a piece of plank, as the line joining them will be the datum from which all horizontal angles and measurements are made, both for the mill and the motive power.

From this line the foundation pit can be marked off and excavated as

a trench extending the whole length of the mill, the width of the trench being sufficient to allow working room on each side of the mortar blocks; about 2 ft. on each side will do. The excavation must be carried down until the bottom is on rock, or in hard pick ground; when the piles are supplied with the mill the pit may require extra depth in order to bring the tops of the piles to the correct level. The bottom of the trench is then carefully levelled. As a rule concrete is not used, and if the pit has been carried to a greater depth than the piles allow for, this material may be employed to make up the difference; if used, the layer should not in any case be less than a foot thick. When the bottom of the trench has been worked as nearly level as possible, a thin layer of sand fills up little inequalities and affords a fair surface to receive the piles.

These piles are now lowered into the pit and bolted together, the blocks for the different mortars are spaced the right distance apart and lined up with the datum line, the height of the posts enabling this line to pass over the tops of all the blocks.

When correctly placed, the mortar blocks are seldom bedded around with concrete, but the material dug from the trench is filled in again, in layers about 6 in. thick, each layer being damped and well rammed. If this is thoroughly done there will be no settlement either in the blocks or in the ground around them.

If the tops of the mortar blocks are not all of the same height, they should be worked down until all are even, the finished surface of each block showing just perceptibly hollow when a straight-edge is laid across it from front to rear.

The batteries would work just as well if the mortars stood at different levels, but the cost of making them uniform in height is trifling, the laying out of other work is assisted, and the general effect improved.

The framework is taken in hand next, and the mud cills placed in position, two in front of, and two behind the mortar blocks; they are roughly levelled, squared with the datum line, correctly spaced, and adjusted fore and aft until the bolt holes are the right distance from the centre. In a mill which ran regularly at 103 to 105 drops a minute, these cills were replaced by concrete foundations 6 ft. deep. The frame, if of the ordinary A shape, may now be put together, the post, sole-piece, and strut being well tightened, and the complete frames raised into vertical position between the blocks. When the framing is connected with the ore bins, as in Fig. 73, the main posts of the batteries and the framing for the bins are erected together, and braced as the work proceeds, the front posts of the bin frames being generally footed on the battery sole-pieces. In very sloping sites the retaining wall is sometimes brought forward to support the fronts of the bins, but such an arrangement leaves a cramped feeding-floor. The three posts for each battery may be braced together by the

top guide bearers, but no bracing should be tightened up until the final adjustments for level and position have been made.

The cam shaft bearings are now bolted up and levelled by adjusting the height of the mud cills. As the battery posts now prevent the datum line from being stretched over the mortar blocks, a parallel line must be set off, from which the cam shaft bearings are located. A preferable plan is to trace the original line across the top of each mortar block before erecting the battery posts; it is then easy to plumb to this line from a staff placed against the sides of the cam shaft bearings. These two centre lines, that of the cam shaft and mortar block, will be parallel, but will not coincide, since they are distant from each other the semi-diameter of the generating circle from which the face of the cam was struck out.

The bearings for the line shaft are now bolted to the sole pieces, the mud cills well packed underneath with broken stone, and the floor around them filled in and rammed solid.

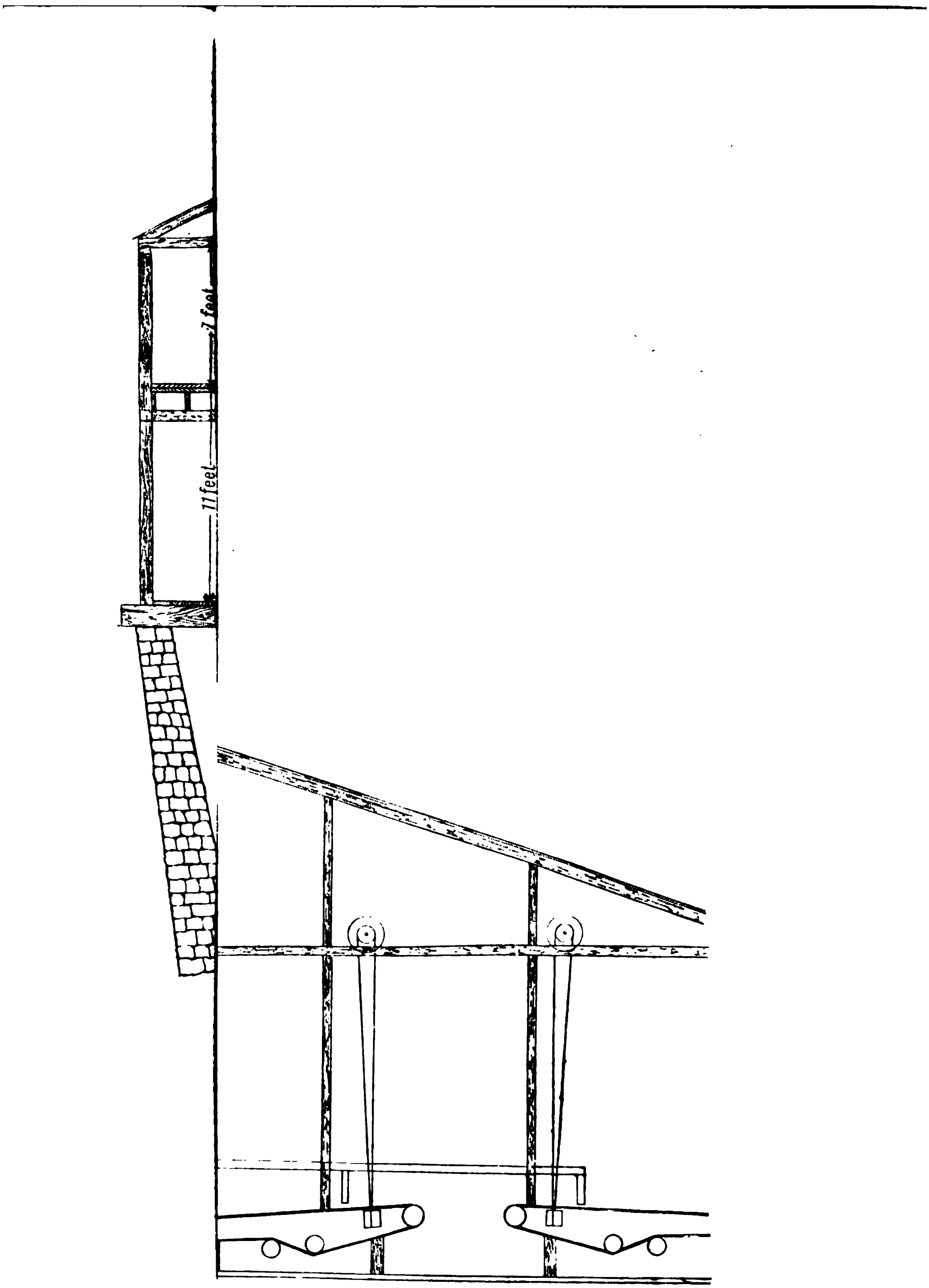
The mortars are lifted on to their blocks by tackle suspended from the upper guide bearers; they are adjusted until their centres are parallel with and the right distance from the centre of the cam shaft, when the holes for the bolts securing them to the blocks may be marked and bored. A template of the bottom of the first mortar may be tried on the others, and if all the bolt holes are similarly spaced, the remaining blocks may be marked off from the template.

Particular care must be taken that the mortar does not bear hardest on the centre of the block; if so, the block requires easing in the centre, otherwise the mortar will rock with the fall of the stamps, and no amount of screwing down will prevent its doing so. A sheet of rubber or tarred felting is interposed between the mortar and the block to afford an even bearing surface, and prevent water from leaking down among the piles or into the end grain of the timber.

All the principal parts of the battery proper are now in position; the remainder of the work is a mere assembling of details.

The cam shafts may be hoisted into their bearings, and when the holes for the stems are correctly spaced in the guides, the cams may be keyed up before the shaft is lifted; if, however, the guides have been made at the mine, it will be safer to set the cams after the stems are in position. Before placing the tappets on the stems, it is well to drive the keys fully in, and see if the gib projects a sixteenth of an inch into the bore of the tappet; each tappet should be an easy sliding fit on the stem, and the ends of the keys should not project unequally when tightened up. Both heads and shoes must be put on before the tappets can be finally set; should there be difficulty in keeping any particular head on its stem, a sheet of emery cloth wrapped around the tapered part of the latter will generally effect a cure.

The water-service pipe is usually led beneath the tables, with a rising



[To face p. 188.

pipe to each pair of batteries, this pipe being fitted with a tee piece connecting the hose for washing the tables. The horizontal branches from the upper end of the rising pipe are stayed to the battery posts and fitted with a valve at each end of the mortar and also in the centre. All service pipes must be well put together; if screwed, the threads must be a good fit, and well screwed home, the vibration of the battery being trying to all pipe joints.

The amalgamating tables are generally made the full width of the mortar, the object being to maintain an even flow and avoid side eddies. The inclination per foot varies with the character of the ore, gauge of screen, and quantity of water used; 1¼ and 1½ in. are the average falls allowed, the extremes being 1 and 2 in. The simplest way of making a table thoroughly tight at the sides is to bend each side of the copper plate upwards for three-quarters of an inch, and secure the upturned edge to the frame of the table with a few screws. The silver plates supplied with the mill are presumably covered with 1 oz. of silver to the square foot, but it is generally admitted that an amalgamated surface is softer and more easily kept in order than a plated one.

The copper plate, which must be well annealed, is bedded down perfectly flat on the table, and all bumps and hollows removed. It is then washed with a strong soda solution, flooded with water, and rubbed bright with a nitric acid solution, 1 oz. to 1 pint; after being well flooded with water, it is cleaned with a cyanide solution, 1 oz. to 1 quart, and quicksilver rubbed into the brightened surface. To prevent oxidation, the surface is either kept under water, or covered with a solution of cream of tartar, made up like whitewash; the surface will also be tarnished by contact with any surface containing sulphur, such as vulcanised rubber.

The **Water Supply** cannot be given as so many gallons per head or per hour, since it depends on the character of the ore, the gauge of the screen, and the inclination of the tables. It may be safely put at between 1,500 and 2,000 gals. per ton treated; of this quantity from 70 to 75 per cent. may be returned and used again. In this way a supply of 60 gals. a minute may serve for a mill of forty or fifty stamps, and in West Australia ore has been treated at a loss of only 300 gals. of water per ton. Dirty, slimy water should not be used; salt water is not prejudicial, except in amalgamating brightened iron surfaces. A supply that has been warmed, in surface condensers or otherwise, keeps the mercury lively and tables soft; hot water makes the mercury too lively, and it runs down the table, leaving the surface hard; very cold water also keeps the plates hard.

The quantity admitted to each mortar is governed by the requirements of the table, the amount used being the smallest that will keep the table clear of deposit.

Ore Feeders.—It is doubtful if mechanical feeding can equal intelligent hand work, but the latter is difficult to maintain, as those who are intelligent enough to feed well tire and grow careless over so monotonous a task. Machine work is certainly better than the average hand work, and the machines that feed by a revolving table are generally preferred to those with a shaking motion.

All self-feeders receive their ore supply direct from the bin; they are

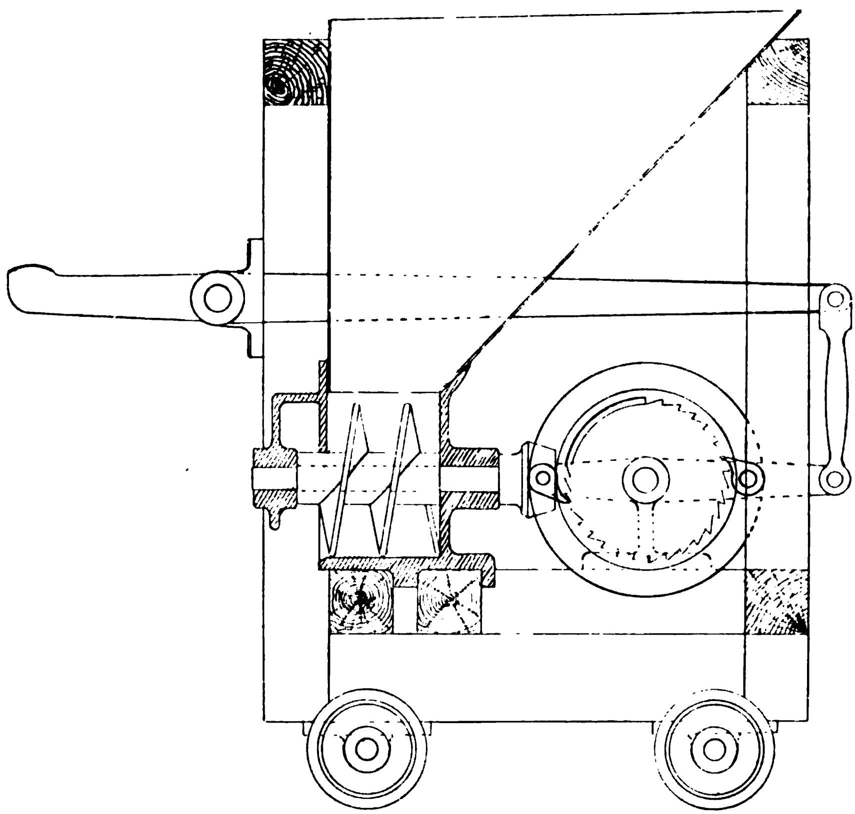


FIG. 74.—Ore Feeder, with Screw Action.

worked by the centre stamp, and are either mounted on or suspended from rails, so that they may be run out of the way when access is required to the back of the battery.

Fig. 74 gives an idea of the general arrangement of a feeder; the collar on the stamp stem depresses the projecting end of the lever, and the motion is communicated through bevel wheels to the feed screw. This machine would give very fair results if the feed screw were made

with a coarser pitch, but there is no doubt the Challenge is the most popular type.

Rock Breakers.—When the ore supply for the mill is hand broken it is generally coarse and irregular in size, requiring a high stamp drop and necessitating a slow speed. Rock breakers increase the output of the mill by providing a properly graded feed, thereby permitting a short drop and high speed. They also reduce the wear of stamp shoes per ton of ore crushed. In one case when accounts were carefully kept, this wear amounted to 1.4 pence per ton of hand-broken ore, and was reduced to .85 of a penny when breakers were installed.

Whether placed in the mill or, as is more usual when the ore is sorted, in the headgear, the breakers stand either at the foot of the grizzly or below the coarse ore bins. In the latter case they draw their supply direct from the bins.

The swinging jaw receives its motion from an eccentric shaft through a connecting rod and toggles; by these means the fixed and swinging jaws are forced together, while the backward stroke is made by spring pressure. The rapid reciprocating motion requires a solid foundation to absorb the vibration. This is afforded by mounting the machine on concrete piers, by bolting it to some heavy structure, or to timber horses well bedded in concrete.

The size of the product is adjusted by tightening the wedge at the back of the rear toggle; the same wedge also compensates wear in the jaws. When the wedge has been drawn up to its full extent longer toggles are inserted.

As these machines are generally designed for making road metal, they are furnished with jaws intended to cube, not crush, the rock. In battery work the object is to crush, and the corrugated or grooved jaws may be dispensed with, and better results obtained with plain, flat slabs of steel. Jaws of this shape may not only be turned end for end, but in case of emergency may be reversed, provided the worn face is well bedded to the jaw with white metal. The wear being heaviest at the lower part of each jaw, in most modern machines the jaw faces are made in sections, which are not only reversible, but those on the fixed jaw are interchangeable with the swinging jaw face. This is a great improvement, as it is no longer necessary to keep two sizes and patterns of jaw faces in stock. The average life of a cast-iron jaw is seven months, it costs in wear a penny for each 2½ tons of rock. Steel jaw faces last a year, costing a penny in wear for each 13 tons crushed. The steel alloys, manganese, and nickel steel last longer still, and though their prime cost is higher, they are in the end cheapest for districts where transport is costly.

The size of a stone breaker is the area of its mouth at the top, measured horizontally, and is the size of the largest stone it can take. 15 in. by

10 in. is a size commonly employed in mining. Such a machine will crush about 7 tons an hour, running at 250 revolutions a minute and requiring 12 H.P.

The inconvenience of erecting a separate engine is avoided in some breakers, in which the complete engine forms part of the machine. It may be driven either by steam or compressed air, all the working parts being boxed as a protection against dust.

PARTICULARS OF BLAKE-MARSDEN BREAKERS.

Size.	Tons per Hour.	Width of Belt.	Weight of Frame.	Total Weight.
Inches.		Inches.	Tons.	Tons.
10 × 8	4	4	2¼	4
12 × 10	5¾	4½	2¾	4¾
15 × 10	7½	5½	4	7
20 × 12	11	6½	6	10½
24 × 13	15	8	8¾	15
24 × 19	16½	8½	91	16½

In the above table it may be noticed that the output per hour is just equal to the weight of the machine itself, though this does not hold good for larger sizes.

In old and worn breakers the stroke is shortened by wear on the eccentric part of the shaft. If no spare one is at hand, matters can be improved by recentring it and turning in a lathe. The shaft will be weakened, but much of the original stroke restored. The only part of a breaker causing trouble, beyond the ordinary wear of the jaws, is the spring to the drawback motion. This is especially the case when it happens to be a coiled steel spring bedded in rubber. As a substitute a bar of springy wood is often placed across the rear of the machine.

In the gyratory type of breaker the ore is broken by a cone gyrating or "wobbling" within an inverted cone. The wearing parts do not admit of so much adjustment as in the toggle machine, and therefore cannot be so thoroughly worn out. Owing to the driving surfaces sliding under heavy pressure they require considerable motive power, and want of lubrication may lead to serious consequences, even to twisting off the vertical driving shaft.

Rock breakers require about 1 I.H.P. for each ton crushed per hour.

Steam and other Stamps.

Steam Stamps.—Of the various forms of stamp in which the force of the blow is increased beyond that due to gravity, the steam-actuated one only is extensively used. The cylinder is placed directly over the

mortar, the head and shoe being fastened to the piston rod. The action resembles that of a rock drill, and is so simple that no specially skilled attention is required. When the details are well worked out, as in the Tremain, this machine is suited for preliminary work and test crushings during the development of the mine. It is particularly well adapted to those districts where transport is costly, and forms one of the cheapest installations for testing the value of the ore in bulk. The idea is by no means an untried one, steam stamps being extensively used in the American copper-mines.

Pneumatic Stamps, such as Scholl's and Husband's, are driven by an overhead crank, an air cylinder being interposed between the crank and the stamp shoe. In some patterns the crank is connected to the cylinder, in others to the piston, the result in each case being that the motion of the crank is communicated to the shoe, not by any mechanical connection, but through a cushion of compressed air at each end of the cylinder. The fall of the head is not only accelerated by the pressure of air on the piston, but the drop is always greater than the stroke of the crank, the amount of this excess depending on the speed and compression in the cylinder.

The speed is 140 drops a minute, about 24 tons per head per twenty-four hours is the average duty. It is the large output in proportion to their total weight that has led to their erection in mining districts difficult of access; but the result has not been sufficiently successful to warrant more extended adoption.

The machine consists of numerous carefully fitted parts, and fails to comply with the fundamental principle that the stamp should be built of simple elements easily replaced. The duty of the pneumatic stamp is too high, the value of one stamping unit too great. Not only is it difficult to provide amalgamating area around one stamp that shall be sufficient for the output, but if the stamp be stopped it is equivalent to hanging up a whole battery or two of gravitation heads.

The friction of the working parts exceeds that of the ordinary stamp, while the heating of the compressed air introduces a fresh element of loss.

Spring Stamps.—Machines of various forms in which the force of the blow is increased by the recoil of springs have failed to stand the wear and tear of daily work. The wear on the joints, pins, and connections is very heavy, such parts requiring a thorough overhaul every three or four weeks. With every care in upkeep the efficiency falls off, owing to looseness in the joints. In a battery of eight of these machines the duty fell from 10 tons per head per twenty-four hours, during the trial run, to 25 cwt. per day after a few months' use, and this in spite of constant repair. In most of them the shoe does not revolve, and therefore wears unevenly, the wear being greatest on the side nearest the feed-shoot.

Pans and Settlers.—The duty of the pan is to grind to a still finer state of division the pulp that has already been crushed in stamp or roll mills; a large number of pans, however, are mere washing machines, catching particles of quicksilver and amalgam that have escaped the tables: this is proved by the inordinate life of the dies and mullers. When required to grind and separate the fine particles of gold still adhering to the gangue, the distance between the dies and mullers needs frequent adjustment. This is practically impossible when effected by slight motion given to a hand-wheel already revolving sixty or seventy times a minute with the centre stem, but is easily made by the side lever arrangement shown in Fig. 75.

The average pan is 5 ft. in diameter, makes from sixty-five to seventy-five revolutions a minute, requires about 100 gallons of water an hour, is charged with 10 to 15 cwt. of sand, and treats from 4 to 5 tons per twenty-four hours. Owing to centrifugal action the pulp is carried outwards, to the circumference of the pan, and is here caught by four incurved wings, which direct a constant stream of pulp back to the centre. From the centre it flows outwards through the openings between the dies and mullers, part of the stream being caught and ground by the revolving muller.

The circulation of the pulp, therefore, depends on the curvature given to the feed wings and to the openings between the dies and mullers being tangential to a circle varying with the diameter of the pan; the working conditions affecting the circulation are the speed, amount of the charge, and the consistency of the mixture. The pan, therefore, can only turn in one way—a fact so evident as not to be worth mentioning, had not the author once seen a row of eight gravely revolving in the wrong direction; nor did this happen at the mine, where they treated several hundred tons of ore, before discovering that the battery tables had not been amalgamated.

The pan is raised on timber framing, which rests on cills well bedded in concrete, as there is considerable vibration when working; to facilitate charging, the top of the pan should not be much above the floor from which it is fed.

In Fig. 75 a coarse adjustment is provided by the flat thread screw on the stem; the key is not driven, as it serves merely as a stop to prevent the screw from revolving without driving the muller frame. The bevel wheel on the stem is a tapered fit and held by a cross cotter, the usual vertical key being difficult to tighten in so cramped a situation.

The dies and mullers have projections cast on them, which fit into dovetailed taper recesses and are secured by pieces of hard wood filling the remainder of the recesses; they last from two to three months. Each pan requires from 5 to 6 H.P., and the cost of treatment is from tenpence to a shilling per ton.

The settlers, now seldom used, are placed at a low level, to receive the

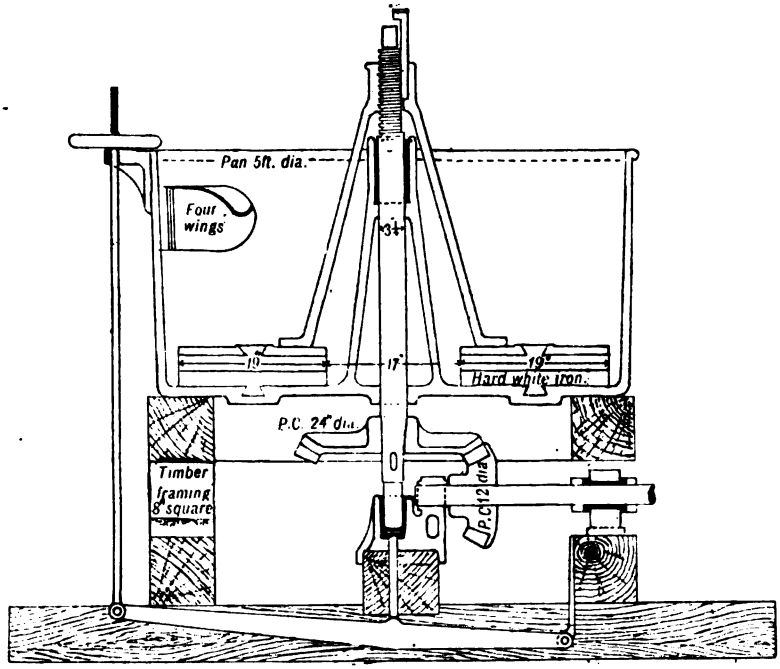


FIG. 75.—Sectional View of Grinding Pan.

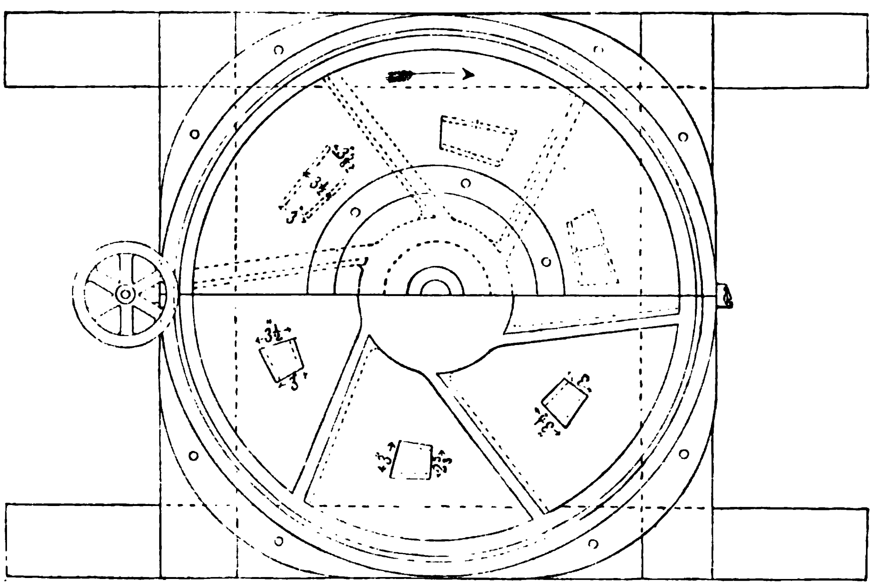


FIG. 76.—Plan of Grinding Pan, Muller Frame removed in lower half.

discharge from the pans; they require 120 gallons of water an hour on the average, and are speeded at twelve to fifteen revolutions.

Grinding.—Although the stamp is an excellent machine for crushing ore to such a size as will liberate most of the gold, it is not always the most suitable means for reducing the gangue to a very finely divided state; as, when the die is covered with a layer of fine pulp, the blow of the descending stamp is cushioned and its effect destroyed.

Even if the layer be a thin one, as the whole surface of the shoe and die are never in accurate contact, the blow takes effect on a few points on which the pulp is crushed to an impalpable powder, or slimed; while such parts of the crushing surfaces as fail to make contact by a thirty-second of an inch will be almost useless. To do good duty under these conditions the stamps must work practically metal to metal, and the resulting jar is destructive to the whole battery.

Evidently the blow of a falling weight is not the best means for subdividing an already fine material, and a substitute is found in the grinding action of pans, ball and tube mills. Rolls are not satisfactory for very fine grinding, being too slow, on account of the number of times the gangue has to pass through them before the whole is reduced to the size required.

Dry crushing is essential in dealing with ores in which part of the value is soluble, and grinding mills are adapted to this process to a greater extent than the stamp, the latter being handicapped when worked without water.

The Ball Mill consists of a drum, protected on the inside by lining plates, covered by a housing, and mounted on a revolving axle driven by belt and spur gearing. The grinding plates are bolted around the inner circumference of the drum, each plate is curved inwards, the whole series forming a succession of steps, and through the openings left between them the ore has access to the screens. The fine screens are protected by coarser ones, the whole being arranged so as to entirely surround the crushing surfaces. The material to be ground, and water, if used, are introduced automatically through a side hopper, while the finished product is delivered to a bin below the mill.

A medium size mill will contain half a ton of steel balls; these grind the material by rubbing contact with each other and with the lining plates, also by constantly dropping from one lining plate to the next. Old shoes and dies and scrap steel are not efficient substitutes for the round revolving ball. While the drum revolves, the material within is in constant motion, passing frequently over the screen surface and being free to leave directly it is crushed to sufficient fineness; the result is a uniform product with a minimum of sliming. The whole process is automatic, requiring little attention; while the wearing parts are all simple castings, easily renewed when worn.

Access to the interior for repair is provided by a manhole in the side of the drum, as the lining plates require renewal about every four months; the whole of the interior may be relined in half a day, and with this exception the process is a continuous one, the feed of raw material and delivery of finished product being constant.

The erection of so simple a machine calls for no comment; the bearings carrying the drum axle and countershaft are bolted to concrete or masonry piers and raised above ground level to allow delivery of the product below the drum casing. In wet grinding the delivery hopper is filled with water, and as the drum revolves, each screen passes through this water, an arrangement ensuring clean screens and clear perforations.

In dry grinding the material must be absolutely dry; should it contain moisture, instead of being ground to powder, it may be rolled into a flaky product, which cannot pass the screen perforations.

The duty of a medium size mill on average ore is about half a ton an hour passed through a 70-mesh screen.

The following table contains particulars of those manufactured by Krupp, Grusonwerk, who has for many years devoted attention to this form of mill, and whose machines are largely used throughout South America, Mexico, and Australia.

BALL MILLS.

	Machine Number.							
	1	2	3	4	5	6	7	8
Diameter of drum, inches	41	52	63	74	89	89	106	106
Width of drum, inches	28	37	38	39	46	54	46	54
Revolutions of drum, per min.	35	33	30	27	25	25	21	21
Revs. of countershaft, per min.	35	100	105	108	150	150	125	85
Width of belt pulley, inches	5	6	7	8	8½	10	10	10½
Approximate H.P. required	2½	6	11	18	22	27	30	36
Weight of balls, lbs.	330	660	990	1,540	2,420	2,970	3,520	4,400
Weight of mill, packed, tons	2½	5½	7	9½	14	15	17	20

Water required, from 1,000 to 1,200 gallons per ton of ore.

Tube Mills.—While the ball mill may receive the ore as it comes from the stone breaker, the tube mill is used only for crushing an already fine material. Unlike ball mills, they have no screens, and a charge of flint stones takes the place of the steel balls. The mill consists of a wrought-iron tube, lined with protecting plates, and mounted on hollow trunnions through which the material is fed and delivered. The tube is 13 ft. or more in length by about 4 ft. in diameter. In the larger sizes the tube is surrounded by a ring which revolves on rollers and takes most

of the weight from the rear bearing, in fact this bearing may then be dispensed with. Motive power can be supplied through either spur or bevel gearing; when two or more mills are to be driven from the same shafting, the latter arrangement is more suitable.

In addition to the sand and water, each mill contains a charge of from 3 to 7 tons of flints, and from 10 to 20 cwt. of these flints will be worn out each month. The larger stones are most effective, and it is usual to pick over the charge at intervals, replacing worn stones by new ones.

About 4 or 5 cwt. will be worn each month from the lining plates, a complete set lasting four months on an average. The output depends on the degree of fineness required, and varies from 25 to 75 tons of finished product per day. The largest output is obtained when a large quantity, from 100 to 200 tons, daily is passed through the mill, and, after sizing, the coarser parts returned for re-treatment. The feed and delivery are continuous, the treated product being generally passed through Spitzkasten and sized, the coarser parts being returned to the feed end.

The following table gives particulars of the sizes of mills in general use. The power required is conservatively stated, and will usually be from 20 to 25 per cent. less than the table states.

TUBE MILLS.

Length of tube, feet	13	19¾	19¾	26¼	16½	23	16½	26
Diameter of tube, inches	43	43	47	47	53	53	59	59
Revolutions per minute	31	31	29	29	28	28	26	26
Width of belt, inches	10	10	10	11½	10	11½	11½	12½
Revolutions, countershaft	108	108	114	114	114	114	114	114
Approximate horse-power	24	32	40	50	45	58	56	80
Weight of flints, tons	3	4½	5½	7½	6	8½	7	11
Weight of mill, cwts.	160	200	260	300	290	340	330	420

Rolls are generally used in the reduction of complex ores from which the mineral is subsequently extracted by concentration. They often form an intermediate step between the rock breaker and some grinding machine, such as a ball mill. When the crushing is done entirely by rolls, two, if not three, sets are required. In the course of its passage through the mill the ore goes from the rock breaker to the coarse rolls and screens, then to the fine rolls and screens, all that is not yet reduced to the required fineness being returned to the fine rolls or passed on to another set for further treatment. If the use of elevators is to be avoided the mill must provide sufficient fall for at least two sets of rolls and their screens, in addition to the fall needed by the concentrators; this means a clear fall of about 45 ft. below the ore delivery level.

The rolls employed at any mill are preferably all of the same size and

pattern, so that worn shells from the fine rolls may be transferred to the coarse ones.

The roll shafts revolve in opposite directions, one being driven by a crossed, and the other by an open belt. On each shaft is keyed a body piece, to which the shells are secured. The simplest way of attaching them is by two or more keys driven between the shell and the body; but this means that the shell must be soft enough to be machined, and a further objection is that the keys are liable to split the shells when worn thin.

The alternative is to make the body in two pieces, one fixed to, and the other sliding on, the shaft, both being turned taper, while the shell is ground to similar taper inside. After the shell is placed between the body pieces, the loose or sliding half is drawn towards the fixed half by through bolts; the double cones not only hold the shell firmly but also centre it.

The bearings of one roll are fixed, while those of the other slide on the frame of the machine; strong springs press on the free roll, forcing it towards the fixed one. The roll shells do not work in contact with each other, but are set apart according to gauge of product required, both the distance and the pressure being regulated by nuts on the spring spindles. Owing to this arrangement the spring pressure is only on the ore crushed, and does not cause unnecessary friction in the shaft bearings.

In the Krom roll pattern the free roll and its shaft are mounted on two rockers working on a fixed shaft. The two roll shafts are thus kept parallel with each other, and unequal spring pressure is less likely to cause uneven wear on the shells. The life of the shells depends on the hardness of the material treated and the size to which it is reduced. An average life would be ten thousand tons on the fine rolls, and an equal output when removed to the coarse rolls.

The plain shell wears better than a corrugated or grooved one, and is able to seize any pieces of ore delivered from an ordinary stone breaker. The wear is in a great measure under control, and the shell surfaces can be kept even by directing the feed on to the highest parts. When once worn to a really bad surface, the coarse rolls throw too much work on the fine, and the fine require several more passages of the ore than should be necessary; in this way the capacity of the whole mill is reduced until the shells are changed.

The process may be either a wet or a dry one, frequently the coarse rolls work dry, water being added to the ore before the fine crushing; the wear of the shells is rather more even when water is used.

Rolls vary in diameter and length from 20 in. by 10 in. to 36 in. by 15 in., they make from 60 to 100 revolutions a minute, and require from 8 to 20 H.P. The strains are severe but contained within the machine itself; to absorb vibration the frame is usually secured to timbers built into the structure of the mill.

Fig. 77 illustrates the arrangement of parts in a Krom pattern roll, C C being the shafts, B B the body pieces or centres, A A the shells. The shaft on the right works in fixed bearings, while that on the left is carried on rockers pivoted on the shaft shown passing through the frame. The pair of rolls is surrounded by a housing, the ore being delivered into the feed shoot on top of the housing by some form of self-feeder. The position of the bearers on which the machine rests should be at right angles to that shown in the illustration.

With the exception of the shells, the only parts subject to heavy wear

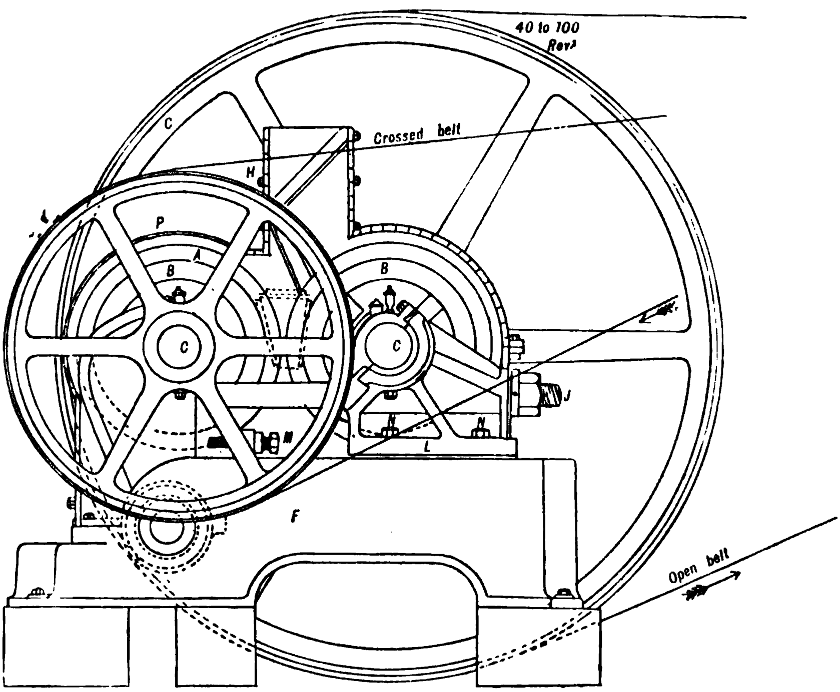


FIG. 77.—Krom Rolls.

are the bearings in which the shafts work; they are generally lined with white metal and need renewal about every six months.

The old metal lining is first removed, the bearing thoroughly heated, and centred around the shaft, any space at the ends being luted up with clay; the metal should be poured directly it is melted, relying on the heat of the bearing to prevent a chill and a bad pouring. A light trimming with a file, and the hole bored and grooves cut for lubrication, and the bearing may be replaced for immediate use.

The two essentials in relining a bearing are—(1) a well-heated casing; (2) the white metal heated to a temperature no higher than is necessary for fusion. Care must be taken that end play does not develop in the shaft bearings, otherwise the shells may no longer face each other accurately, and a ridge of gradually increasing thickness will remain on alternate edges of the rolls.

CHAPTER XII.

CONCENTRATING AND GOLD-EXTRACTING PLANT.

Concentrators—Percussion Tables—Jigs—Wilfley and Buss Tables—Cyanide Plant—Capacity, Size, and Shape of Vats—Arrangement and Construction—Foundations—Equipment.

THE machines described in the last chapter are used for reducing the ore and liberating the mineral from the gangue; concentrating machines deal with the pulverised ore, and separate the mineral from the gangue by taking advantage of the difference in the specific gravity of the two substances. Concentration would be impossible if this difference did not exist.

In no case is the operation perfectly performed, the product may contain all the mineral, but gangue will be included; or the mineral may be clean and a percentage of it lost, the amount varying with the efficiency of the machine. In every case the process is assisted by sizing beforehand, and the closer the sizing the cleaner the concentrates will generally be.

Most machines present, in some form or other, an inclined surface, the material to be treated being delivered near the upper end, and washed downwards by the flow of water. The heavier mineral tends to lag behind and is assisted in doing so by a shaking motion imparted to the inclined surface, which causes it to "bed." In the simplest machines the finished product is not delivered, but has to be removed at intervals; in more complex machines it is not only delivered but graded into different qualities.

It is owing to this percussive or shaking action, combined with the usually sloppy state of the concentrator floor, that the machines require substantial foundations; if settlement occurs, or want of rigidity allows other motions to develop, the working of the machine is at once affected. The mud cills supporting the frame should rest on a flooring of concrete, the spaces between them be filled with concrete, and the surface either decked with planking, or cemented.

The **Percussion Table** is, next to the buddle, one of the simplest forms of concentrating machine; the pulp is received on a suspended bed, with two or more shallow depressions in its upper surface. This bed, or

table, is about 12 ft. long by 6 ft. wide, and receives a slight motion in the direction of its length from a cam with three arms; on leaving the toe of the cam the bed is pushed back by a spring, the return stroke ending abruptly against a buffer.

The shake thus imparted to the pulp beds the mineral in the depressions in the bed, while the gangue is carried away by the overflow of water; in this case there is no delivery of the finished product, and the depressions must be cleaned out at intervals as they become filled. The inclination of the table can be adjusted by the suspension bolts, the force of the blow by the spring, and the length of stroke by altering the bumper head. The construction is so simple that a trial machine can be built on any mine possessing the usual equipment of tools, and a small table, about 6 ft. by 4 ft., is often useful in determining to what extent the ore is amenable to concentration.

The **Jig** is another simple form, and consists of a hutch filled with water, the screens containing the ore being either plunged up and down in the water, or the water made to pulsate through them by the movement of a piston. The jigs in each row work in series, the overflow from the first being treated again in the second; and in each row the speed, length of stroke, and mesh of screen are suited to the size of ore fed.

Thus if there are three coarse jigs, dealing with ore about the size of small peas and rice grains, they will be speeded to 150 revs. a minute, the stroke of the first will be 1 in., of the second $\frac{7}{8}$, and of the third $\frac{3}{4}$ of an inch; the screens will be 10 to 12 mesh.

The second jigs will run 200 revs. per minute, with strokes of $\frac{5}{8}$ in., $\frac{1}{2}$ in., and $\frac{3}{8}$ in., the screens being 12 and 14 mesh. The third row, with screens of 14 and 16 mesh, will run 250 revs., and have strokes varying from $\frac{5}{16}$ to $\frac{3}{16}$ in.

Slime jigs are run at 300 strokes of $\frac{1}{8}$ to $\frac{1}{16}$ of an inch, and have screens of 20 and 24 mesh—though slimes are generally treated on some form of table, the jig being essentially a machine for handling a coarsely broken material.

Motion is derived from an overhead shaft with adjustable eccentrics connected to the pistons or sieves; repair consists almost entirely in renewal of worn screens, though it is worth noting that the sides of iron hutches are often insufficiently stayed and they spring with the strokes of the machine. This not only leads to leakage at the joints, but detracts from the effect of the pulsation.

As a rule two or more jigs are combined and form separate compartments in the same hutch; the clean mineral is withdrawn from the bottom of the compartment, that which is too coarse to pass through the screen being removed when the bed gets too heavy.

Each complete machine requires on an average $\frac{1}{2}$ H.P., and uses

25 gals. of water a minute, treating about 20 tons of ore per twenty-four hours.

The **Centrifugal Concentrator** imitates the movements given to a batea, the round pan is mounted on a hollow vertical axis, and rotated by bevel gear, the rotation being changed into a series of irregular impulses by a small crank. The pan itself is about 5 ft. in diameter, the highest point in the bottom being midway between the centre and the circumference; from this point the bottom slopes towards the waste pipe in the centre, and to the ore bed towards the rim. Adjustable gates in the bottom of the pan near the circumference allow the finished product to pass into a circular receiving launder.

As generally arranged, three machines treat the pulp from ten heads of stamps, two of them taking the tailings direct from the amalgamating tables and delivering the half-finished product to the third. Concentration is rapidly effected, and the product a clean one; but the wear and upkeep of the machine is heavy, owing to the constantly checked momentum of the pan and its contents.

In the **Frue Vanner**, illustrated in Fig. 78, the table consists of an inclined endless belt passing over rollers at each end of the machine; the working surface of the belt is 4 ft. wide by 12 ft. long, it may be plain or corrugated, and the edges are flanged upwards. The belt slopes at an incline of $\frac{1}{4}$ to $\frac{1}{2}$ in. in the foot; it travels from 4 to 12 ft. a minute towards its upper end, and receives a rapid shake in a direction at right angles to its length. The pulp is fed from a distribution box about 3 ft. from the higher part of the machine, and is played on by jets of water as it is carried upwards by the travel of the belt. The mineral, assisted by the shaking action, clings to the belt, is carried over the higher end and deposited in a trough beneath the vanner, the gangue being carried away to the lower end of the belt by the flow of water.

Vanners always stand at right angles to the shafting driving them, and are therefore worked by quarter-twist belts (see Chapter XIII.); they require a uniform speed of from 200 to 210 revs. per minute, and treat from 5 to 10 tons in twenty-four hours, according to the class of ore. Although of limited capacity, they give excellent results in the hands of those accustomed to use them, but their successful working depends on more or less delicate adjustment, and in charge of inexperienced persons they are capable of tricks beyond the ordinary power of inert matter.

The **Wilfley Concentrator**, although a modern invention, may be found in almost every gold-mining district, one copper-mine having no less than five hundred of them at work; it has a greater capacity than the vanner and does not require the same skilled attendance.

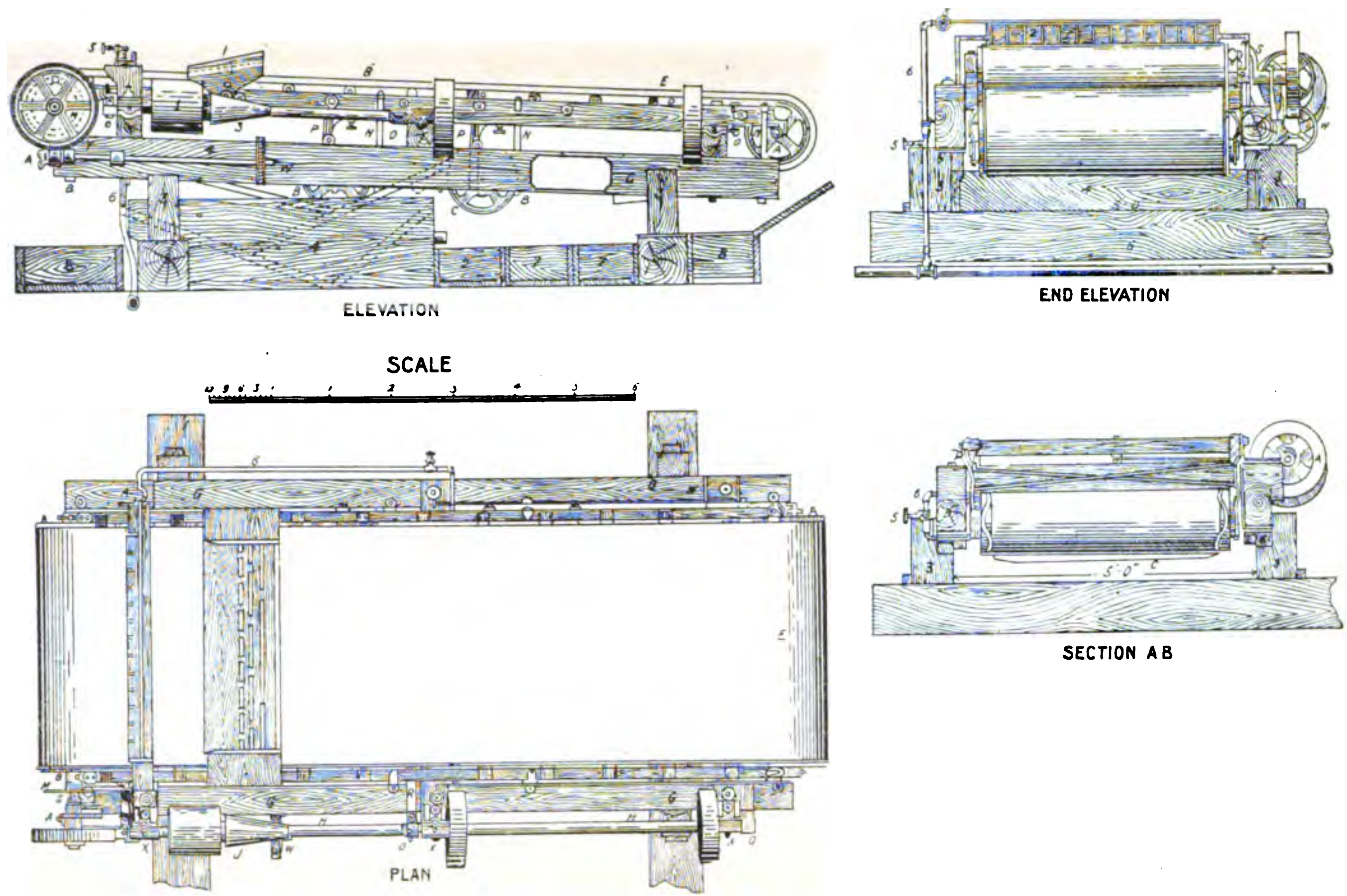


Fig. 78.—Frue Vanner.

The flat oscillating table on which the ore is treated is made of timber and covered with linoleum, part of the surface is corrugated with ribs of gradually decreasing length. The amount of motion may be adjusted, but three-quarters of an inch is the average for all round work. A raff wheel forms part of the machine and returns the middlings; it also acts as a sort of governor, preventing waste when the quantity delivered to the machine is more than it can deal with. When the feed is not in excess, the delivery from the raff wheel consists of pulp in which the mineral is imperfectly separated from the gangue.

The whole machine is self-contained and easily erected, being carried on a longitudinal girder resting on three feet, which are bolted either to concrete piers or to the floor of the concentrator house. Each table requires about 200 gals. of water an hour, and is driven by a 4-in. belt, the driving pulley making 240 revs. per minute; the quantity treated daily varies from 12 to 40 tons. The Wilfley is being successfully used on slimes, the concentrates produced being about 7 per cent. of the quantity treated, and containing 70 per cent. of the assay value of the tonnage. As in other vanners, the pulp is delivered at the higher end, and washed towards the lower side by a thin film of water, the rate of flow being regulated by the adjustable inclination of the table. It should be noted that the flow of water is at right angles to the travel of the pulp, the bulk of the water, therefore, flows off with the gangue, leaving the concentrates relatively dry. On reaching the delivery side the pulp is separated into concentrates, middlings, and tailings. Each table is 17½ ft. long by 6 ft. wide, requires 1 H.P., and weighs 32 cwt. when packed.

The **Ferraris Table,** made by Krupp, resembles the Wilfley in many respects; it has a wooden table covered with linoleum supported on hinges or springs, and subjected to a rapid and variable end shake by two eccentrics. The table proper is supported by an iron frame, has longitudinal corrugations, as in the Wilfley, and the inclination can be varied to suit different ores.

The pulp is delivered near one end on the higher side, water in adjustable jets being supplied at the same side; the gangue is washed to the opposite side, and the concentrates delivered at the opposite end. Two patterns are made, one for coarse, and the other for slime treatment. Each table is 11½ ft. by 5 ft., requires about half a horse-power, and from 4 to 9 gals. of water a minute, runs at 340 vibrations, and treats about half a ton an hour.

The **Buss Table** is similar to the last machines described, the pulp being treated on an inclined flat table with corrugations; the motion, however, is altogether different, as the table is free to rock on the vertical springs supporting it.

There are four rows of these wooden springs, placed vertically beneath the bed, and the end shake imparted by an eccentric causes the table to travel in an arc of a circle.

This motion is not as simple as it appears, for if the springs be vertical when the eccentric is at the middle of its stroke—while the driving shaft revolves once—the table will travel to the lowest point of its arc at one end of the stroke, back to the lowest point at the opposite end of its stroke, and return to its original position. But as the springs are long when compared with the length of the stroke, the vertical movement is almost eliminated in this case. If the springs are vertical when the eccentric is at one end of its stroke, there will be but one highest and one lowest point of the table during each revolution of the driver. Or the table may be so set that the springs do not reach the vertical position at any part of their vibration. By varying the adjustment of the machine greater prominence can be given to either of the components of this compound motion; the longitudinal traverse or stroke can be set by altering the eccentric, and the angle of the springs, or vertical movement of the table, by altering the length of the connecting rod.

The table itself is supported on a frame, and by the elevating screws provided the inclination of the working surface with regard to the frame may be altered; by these means different inclinations can be given to opposite ends of the table.

It is evident the range of adjustment is considerable; the flow of the water film across the surface may be regulated both in quantity and speed, and will be in constant agitation during its passage to the lower side. Each table is 16 ft. long by 7½ ft. wide at the large end, the motive force does not exceed half a horse-power, and the pulp is generally delivered to the machine as it leaves the battery. Each table treats on an average 20 to 25 tons per twenty-four hours.

The simplest method of erection is to support the lower frame on cills parallel with the length of the table, the two centre ones being extended to carry the driving shaft and bearings; these cills should be bedded in, and bolted in concrete. The wearing parts are few and the wear light, provided the foundation is sufficiently stable to prevent any racking between the driving shaft and table.

Cyanide Plant.—As the tonnage to be handled in this process is generally considerable, the location of the site is an important feature, economic conditions being fulfilled in one that permits automatic filling and offers sufficient fall both for the process itself and the discharge of the residues. An ideal site, with fall to the required amount, is seldom available; and owing to the grade required to prevent settlement of pulp in the tailings launders, which amounts to at least 3 ft. in 100 ft., advantage cannot be taken of more favourable ground at some distance from the battery.

In laying out a plant for direct filling, the levels for grading the site will be taken from the delivery launder below the mill, and if vats 10 ft. high are to be used, a fall of 25 ft. will be required. This fall may be reduced by using vats of less height, or by discharging at the side instead of beneath; on the other hand, an increase in height is advisable to allow for disposal of the residues. Should the tailings require previous settling to eliminate slimes, the fall must be increased by the height of the additional vat and discharge room; so that the leaching qualities of the material to be treated must be ascertained before the amount of fall can be determined. Although sometimes advisable, there is no mechanical advantage in securing direct filling at the expense of a site so low that the residues require elevating after treatment.

In treating old tailings, or accumulations from settling pits or dams, hoisting is always necessary, an elevation of 25 to 30 ft. being sufficient to allow for discharge of residues. In this case a site is selected which can be commanded by an incline track, the tailings being hoisted in waggons or self-dumping skips. The skips used are generally open at the top, and are made to dump into any particular vat by cramping across the track a horse, or frame, up which the back wheels run.

Capacity.—The capacity of the plant is determined by the quantity to be treated daily, the time required for treatment, and for charging and discharging the vats—the time occupied in treatment depending on the character of the ore and the facility it offers to percolation. If 100 tons are to be treated daily in vats of 100 tons capacity, one vat will be filled each day; if three days are required for treatment and half a day for discharging, five vats would be the smallest number for the duty. The same quantity might also be treated in seven vats of 50 tons capacity, requiring only half a day each for filling.

Size of Vats.—The capacity of a vat is its area multiplied by its height, and vats of any required capacity may be built by allowing from 27 to 30 cub. ft. for each ton they are to contain. Even an allowance of 30 cub. ft. to the ton may be insufficient if a large proportion of light slimes is included, and in every case a foot must be added to the height decided on, to allow for the depth occupied by the filter. The question whether large or small vats shall be used depends chiefly on the character of the material to be treated; large vats fill slowly and allow a considerable proportion of the slimes to settle; small ones fill quickly and the contents may be unnecessarily clean, gold being lost in the overflow.

In dealing with deposits of old tailings that have been cleaned in their deposition, vats of 40 and 50 ft. diameter are used, and there is no reason why these dimensions should not be exceeded.

An examination and test of the tailings is necessary not only to determine the size of each vat, but the relation between its area and height, for the latter dimension depends on the resistance to percolation in the material to be treated. With clayey, slimy tailings a height of 5 ft. may be all that is expedient without unduly prolonging the process; while with freely percolating material the vats may be made up to 14 and 15 ft. in height. In built vats it is not advisable to exceed this amount, as the pressure near the bottom becomes severe, especially when vacuum percolation is used. Economy in first cost is certainly secured by building vats high in proportion to their diameter; it may be noted the pressure on the sides is proportional to the depth, and does not increase with the diameter.

Shape of Vats.—They may be round or rectangular; the latter shape economises space, as they can be more closely grouped together, and can generally be discharged with greater rapidity, since work may be carried on at more points. The circular shape gives greater capacity for a given weight of constructional material, such vats are easily cleaned, and when made of wood can be tightened in case of leakage.

General Arrangement.—The disposition of the vats must be such as to give the greatest facility for filling and discharging; they are therefore placed in one or more rows, so as to be commanded by straight tracks and tram lines. When arranged in double rows, a track for a travelling steam crane may be laid between them; this method of discharging, with a grab bucket filling a truck at a time, is found economical even where labour is cheap and abundant. The top discharge also saves the 6 or 7 ft. required beneath the vats when they are emptied from the bottom.

Construction.—Vats may be constructed of brickwork, concrete, iron, or wood; in its simplest form the vat is excavated from the ground and lined with either brick or concrete.

The objection to the excavated vat is the difficulty of detecting leakage; settlement may take place in spite of every care in selecting the ground and footing the foundations, and it is therefore safest to have the walls open to inspection from the outside.

In masonry or brick vats, standing entirely above the ground, the thickness of the walls is decided by the height, since height, not diameter, is the factor determining the internal pressure.

The whole of the area is first paved to the outside of the side walls; these walls are footed on the paving, are 4 in. thick at the base for each foot in height, and are given an external batter of 3 in. in a foot commencing at one-third of their total height.

The paving of the bottom generally slopes towards the point at which

the solutions leave; great care is necessary in joining the side walls to the bottom; the interior is finished by a coating of cement plaster.

Iron tanks are light and portable, and are often used for temporary work, and when other materials are not available. The sheets are either bolted or riveted together, and are coated on the inside, so that the solutions do not come into contact with the metal. Asphalt and paraffin wax are generally employed for this purpose; each requires renewal from time to time in abraded places.

Wooden vats are made either round or rectangular in shape, the former being more usual. Rectangular ones are made in the same way as cisterns for pitwork, the bolts being so disposed as to compress the joints and hold the structure together.

In the rectangular pattern the planking used will be 2 in. thick for small vats, 2½ in. for medium sizes, and 3 in. for any size vat likely to be made with ordinary commercial timber. The timber must be well seasoned and the joints carefully made, each plank being planed true on its edges and tried by rubbing on its fellow, until a true surface is obtained. The bottom is held together by ¾-in. bolts, spaced about a foot apart, and running right through the different planks; before being joined together the edges of the planks may be painted with white lead worked with oil to a creamy consistency, but this is not necessary if the edges are well planed. In small vats the bottom projects 6 in. beyond the sides, in larger ones the allowance is increased, and in making a vat 8 ft. by 12 ft. within, the bottom would be 14 ft. by 10 ft.

The side walls enclose the ends, all being made in the same way as the bottom, with the exception of the vertical bolts, which in this case pass right through the bottom and secure it to the sides. This joint requires particular care, sometimes the four sides are bolted together, and dropped into a groove cut to receive them in the bottom; or the groove may be dispensed with, and the lower edges of the side walls faced off to fit the bottom. In either case the joint is tightened by the bolts passing through both sides and bottom.

The sides and ends are stiffened by battens with their lower ends let into the projecting part of the bottom. They are spaced about 2 ft. apart, and alternate pairs are tied together by bolts crossing the top of the vat.

When skilled labour is scarce, leakage may be avoided by making bruised joints, but these will not be successful unless the timber is thoroughly seasoned. In making this form of joint the centre of the planed edge of the plank is pressed down into a groove, the width is immaterial, but generally about ¾ in. These grooves may be made by passing the planks between narrow rollers, or by striking a tool in the shape of a smith's narrow set. In soft woods the depth of the groove will be about $\frac{3}{64}$ in., but less for the harder and less compressible woods.

The upstanding parts of the edge are now planed down level with the bottom of the groove, care being taken not to touch the depressed part. The joint must now be kept dry until the planks are bolted together, when moisture causes the compressed wood beneath the groove to swell and make a perfectly tight joint.

In round vats the bottoms are formed of planks cut radially and planed true on each edge, but the points do not meet in the centre, as the planks are not fastened together in any way, only pressed into close contact by the constriction of the hoops. When the bottom is fitted together, the circumference is trued by a gauge pivoted at the centre of the tank, and when truly circular, the outer edge is worked to the same thickness throughout, as the side planks are generally joggled in about $\frac{3}{4}$ in.

The staves will be free from $2\frac{1}{2}$ to 4 in. thick, according to the size of the vat, their edges are planed radially, and they are joggled to fit the bottom from 4 to 6 in. from their lower ends. The joint is tightened by two belts of round iron, with screwed ends passed through connecting sockets; the sides of the vat being supported by similar belts, spaced 12 to 15 in. apart, and formed of round iron from $\frac{3}{4}$ to $1\frac{1}{8}$ in. in diameter.

In these vats the discharge door is usually fitted in the centre, and the filter supported by a wooden grid.

Foundations.—The foundations must be designed to afford firm support to the vat and its weighty contents, access for inspection, and head room for discharging. Since, therefore, the whole area of the bottom cannot be supported, the weight must be distributed as evenly as possible. Trouble has often been caused by foundations formed of rows of posts, which swayed laterally owing to want of bracing, and settled unequally, as their bearing area was insufficient for the weight to be supported.

Foundations suitable for both masonry and wooden vats are formed by walls of masonry or concrete, arranged in concentric rings, with an interval of 36 to 42 in. between the rings, the edge of the outer wall being well inside the bottom of the vat. The walls are surmounted by timber cap pieces, and a central alleyway is left through all the rings, in which rails are laid for the discharging trucks.

When the foundations are of timber, it is framed into horses, with a vertical post every 3 ft. between the cap and foot pieces, the end bays in each horse being cross-braced to prevent swaying. Such frames are placed in parallel rows 3 ft. apart, and should rest either on concrete piers or bedded cills.

In addition to those vats in which the tailings are settled or leached, others will be required to hold the various solutions and washes; each of these usually has a capacity equal to one-third of the main vats, but more room may be necessary if the treatment is prolonged. They may be

placed above or below the leaching vats, preferably above, as the solutions need not in that case be pumped from the sumps as they are required.

The pumps used for elevating the solutions are generally small centrifugals, installed in duplicate, each being fitted with multiple suction and delivery pipes, enabling it to draw from any sump and deliver to either of the vats. The motive power required is generally about 5 H.P., which suffices for the pumps, zinc lathe, and vacuum pump, though a dynamo for lighting the works is often added.

CHAPTER XIII.

TRANSMISSION OF POWER.

Various Means—Shafting—Couplings—Bearings—Pulleys—Setting out Shafting—Belting—Ropes, cotton, wire—Compressed Air—Electricity—Examples.

THE medium to be employed in a power transmission scheme depends on the purpose for which the power is required, the distance it is to be sent, and the quantity to be transmitted. Distribution and transmission are intimately associated, and as the same means are used in each case, they will be considered as forming part of the same subject; for it would be hard to define where one ends and the other begins. Ordinary shafting, for instance, though generally considered as a distributer, does but convey the power from the motor to the machine; yet there are limits to its use, as no one would seriously propose transmitting power for a quarter of a mile by this means.

If the distance is a short one, there are shafting, belts, cotton ropes, and gear wheels, any of which are suitable, though the latter are only employed when the motion is to be changed in direction, or when the distance is too short for ropes or belts.

For medium distances there are steel ropes and rods. Either will transmit a reciprocating motion, such as is used in pumping, while the wire rope will also convey a rotating motion from one shaft to another.

For long distance transmission there are compressed air and electricity. No rule can be laid down as to the limits within which each means is applicable, and the particular medium chosen will depend largely on local conditions. In every instance, however, a badly designed and ill-constructed arrangement is certain to absorb much of the power it should transmit.

Steam is not included, being the least suitable of all means, and only to be used when there is no other alternative. In transmitting power by steam it should be understood that the quantity of condensed water drained from the pipes is no criterion of the loss involved. The loss is really the difference between the number of heat units placed in the pipe at one end and that available at the other.

Shafting.

The use of shafting is generally limited to some particular house or building, and as arrangements often have to be worked out with the material available at the mine, it will be advisable to state the rules on the subject. The power which may be conveyed by a shaft varies directly with the number of revolutions a minute; if the speed is doubled, the power capacity of the shaft is also doubled.

It varies, too, according to the cube of the diameter of the shafting; and if a shaft 2 in. in diameter transmits 8 H.P. at a given number of revolutions, a shaft 2 by 2 by 2 in., or 8 in. in diameter, will transmit 8 by 8 by 8, or 512 H.P.

When the horse-power and speed are known, the size of shaft required is found by multiplying the horse-power by 70, dividing by the revolutions per minute, and the cube root of the quotient will be the diameter of the shaft in inches. This provides for mild steel shafts; if wrought iron is to be used, multiply by 80 instead of 70.

To find the horse-power that may safely be transmitted by a mild steel shaft, multiply the cube of the diameter in inches by the revolutions per minute, and divide by 70.

In theory it would seem correct that a line of shafting from which power is distributed at intervals should decrease in size the further it extends from the source of power. This is often the case in mill driving: the shaft may be 6 in. in diameter at the engine, and only 3 in. at the further end of the mill.

For general work, however, any small saving in weight or prime cost is more than offset by the additional sizes of pulleys, couplings, and bearings required. In all outlying districts every unnecessary size introduced is a step in the wrong direction, and there seems no reason why one diameter of shafting, say 2½ in., should not serve for machine shops, concentrating house, cyanide plant, and all purposes of minor distribution. Such an arrangement would ensure interchangeability of parts throughout the works as far as shafting is concerned, and those who have faced the predicament know what it is to find the only pulley of the right diameter to be 2 in. too small in the bore.

Shafting is made in lengths, and a line of shafting consists of two or more of these lengths joined together, the joints being made by means of couplings. English practice still adheres to the flanged coupling, although it is difficult to fix, more difficult to remove, requires a more accurate fit than ordinary gauge limit work supplies, and is therefore never true unless faced after it is keyed on.

When a line of shafting "wobbles," the cause can generally be traced to these couplings. Each length of the shaft may be true enough, but the

whole cannot revolve truly unless the face of each half coupling is at right angles to the axis of the shaft.

All this is avoided in the box coupling, which is easily put on and taken off; not only does it centre the ends of the shafts, but will connect them when they differ in diameter.

The box coupling consists of an outer casing bored taper at each end, and conical split wedges, which, drawn together within these tapered recesses by bolts, hold the shafts securely. The first cost is a little higher than that of the flanged coupling, but this may be regarded as an insurance against greater expenses caused by delays and misfits at the mine.

The **Bearings** should be of the swivel type, self-oiling, and self-adjusting on their spherical surfaces. Such a fitting accommodates itself to the shafting, and permits a long wearing surface of cast iron or white metal to replace the ordinary brasses. These bearings are made in halves, each having a turned spherical projection in the centre. These projections swivel in the recesses bored to receive them in the stand holding the two parts of the bearing. They can be fixed in any position, and if required are fitted with a screw adjustment for regulating the height.

The distance between the points of support, or the spacing of the bearings, is determined chiefly by the diameter of the shaft. As a rough rule for general guidance, when the shaft is 2 in. or less in diameter, multiply the diameter in inches by 4, the result is the distance between the bearings in feet; for shafts from 2 in. to 2½ in. multiply by 3.5; above 2½ in. and up to 3 in. multiply by 3. These distances permit distribution of power at intervals, but bearings should if possible be placed to afford support near couplings and at any points where more than an average amount of power is received or delivered.

To prevent end play collars are fixed to the shafting, and are often placed either inside or outside the end bearings. A better arrangement is to fix the two collars at opposite ends of the same bearing, expansion of the shafting cannot then cause increased friction.

Pulleys.—Wrought-iron pulleys are generally preferred, being lighter and less liable to breakage in transport. For convenience in putting on and taking off they are made in halves. When bolted together these halves have sufficient grip on the shafting for ordinary drives, or the friction between shaft and pulley may be increased by placing a sheet of emery cloth between them. For heavier work hollow-backed keys are used, sunk keys being only required for very heavy drives.

The rim of the pulley should be 20 per cent. wider than the belt working on it. A crowned rim helps to steady the belt, especially at high speeds, but if the belt has to work over fast and loose pulleys, the driver should be flat on the rim.

For high-speed work the pulleys must be carefully balanced, or centrifugal strains will be set up and transmitted through the shafting to the bearing; these strains increase with the diameter and speed of the wheel and amount of unbalanced weight.

Loose pulleys are conveniently lubricated by a cup in which a charge of grease, or solid lubricant, is pressed inwards by a spring piston. The lubricant is only fed when required, and such pulleys run for months without attention.

In power transmission by belt pulleys the shafts may be either parallel with or at right angles to each other. The direction of rotation may be reversed, and the speed can be altered. The diameters of the driving and driven pulleys multiplied by their respective revolutions per minute will always be equal quantities. Therefore the number of revolutions in a given time varies inversely as the diameters of the pulleys, and if the driven pulley be half the size of the driver it will make twice as many revolutions.

The rule for determining the diameter or the revolutions of a pulley connected with a known pulley is as follows:—Multiply the diameter by the revolutions of the known pulley, divide by the diameter or revolutions, as the case may be, of the unknown pulley. The quotient is the unknown number, either diameter or revolutions. Hence, to find the diameter of a driving or driven pulley, multiply the diameter of the known pulley by its revolutions and divide by the revolutions of the shaft for which the pulley is required. When the diameter is known and the revolutions are required, divide the product of the first pulley by the diameter of the second. Necessarily the two pulleys must be expressed in the same units, either inches, or feet and fractions of feet. The total power that can be transmitted between two pulleys is greatest when they are of equal diameter, since the power varies directly as the arc of contact between the belt and the pulley. Doubling the arc enables twice as much power to be transmitted, provided the other proportions are sufficiently strong. For this reason it is only under exceptional circumstances that one pulley should be more than four times the diameter of the other.

Setting Out.—Granted that the shafting is proportioned in diameter and speed to the power to be transmitted, there still remain several conditions to be fulfilled. It must be level, straight, parallel with the shafts to which it is connected, its bearings must be aligned to avoid friction, and, if possible, the power should be distributed equally on each side of the shaft. The laying out will require the same care whether the bearings are self-adjusting or not.

In setting out a line of shafting, the first thing required is a line representing its centre. This may be either an extension of one already fixed, such as the crank shaft of an engine, or may be parallel with an existing

line. When both lines of shafting are in the same horizontal plane they may be squared with a line drawn at right angles to them, this being the only instance in which the ordinary square is of any use.

When the shafts are at different levels, the horizontal distance to the new shaft is measured off and a line stretched parallel to and at the same level as the datum. This direction is then transferred in a vertical direction by plumb lines.

The beds on which the bearings rest may now be worked to an even surface; they may be roughly levelled with each other, although it is not likely that the bearings themselves will all be of one height. When the bearings are to be carried on brackets, the faces on which these brackets rest must be perpendicular and equidistant from the centre line.

The bearings are now placed in position and levelled, if necessary, by parallel packing pieces inserted beneath them. The simplest way of levelling is to run a parallel piece of shafting through two bearings, and test it in several places with a level which has a V groove planed out of its bed; this groove ensures agreement between the longitudinal axes of the bubble and the shafting.

The bearings being now levelled and roughly in position, a wire or fine line representing the centre of the shaft is now run through them; they are adjusted until concentric with this line. The position of each bearing may now be pencil marked, and the bolt holes bored. These holes should be in the centre of those in the bearing sole-plates, so that a little room is left for final adjustment.

After the shaft is in position and the driving pulley bolted on, but not permanently fixed, the laying off may be verified by a line stretched along the edges of the driving and driven pulleys. To obtain the best results the line must not be fastened to either pulley, but to a point beyond each. It should not touch either pulley, but cross each in as long a chord as possible. Mark the edge of the pulley where the line crosses it, say at the back, revolve the shaft until the mark is opposite the line in front. If the distances between the pulley edge and the line are equal at front and back, the line and shaft are at right angles to each other. By working to the same mark on the pulley edge the test will be equally effective, whether the edge of the pulley is true or not, but care must be taken that the shaft collars are adjusted so as to prevent end play.

The driving and driven pulleys must each correspond with the line when tested in this way, allowance being made for any difference in the width of the rims. Should any alteration be necessary, the whole length of shafting must be moved, and again tested with a line to prove no deflection has occurred in its length.

If these precautions are observed, the belts will run in the centres of the pulleys, show no disposition to creep to one side, and require neither guides nor rollers to keep them central.

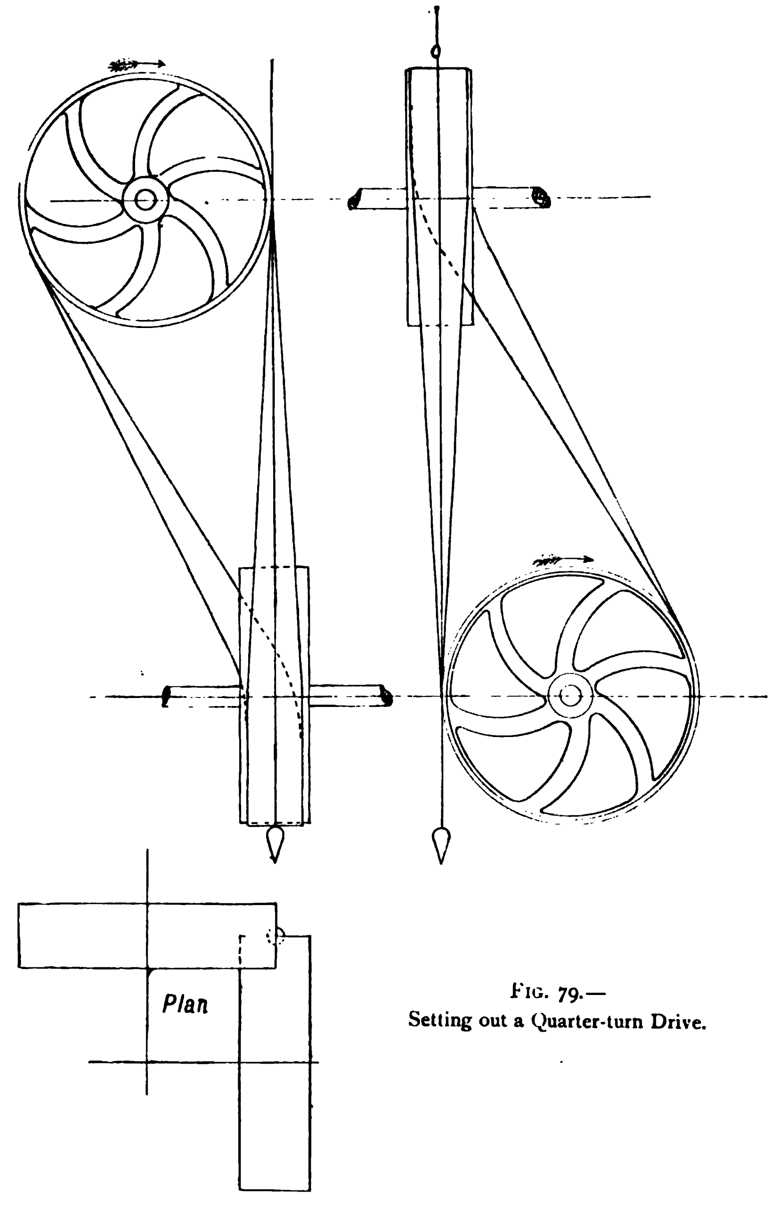


FIG. 79.—
Setting out a Quarter-turn Drive.

When a quarter-turn drive is required, as in vanners and other machines, the two shafts must be at right angles to each other. A plumb line is hung from the centre of the driving face of the upper pulley, and the lower pulley adjusted on its shaft until its face is touched and bisected by the plumb line.

Belts.

Power may be transmitted from one shaft to another by belts, ropes, or chains; the two former are preferred as affording a more flexible drive and less rigid connection. Belts are made of leather, rubber, and various fibrous substances, such as flax, cotton, and hair. Leather belts weigh from 10 to 16 oz. per square foot when double, and vary greatly in quality; a fair idea of the quality being obtained by examining the length of the laps of which it is composed. Good belts have short laps, cut from the best parts of the hide, and not exceeding 4 or 5 ft. in length; inferior belts have laps 7 and 8 ft. long and varying considerably in thickness. This variation may not be observable in the finished belt, as the thin part of one lap is placed against the thick part of another. Leather lasts well if given attention and dressed at intervals with dubbing dressing, or castor oil, though the last should not be used on belts with cemented joints; in any case the surface must be kept soft, so that it laps lovingly around the pulley. The objections to the use of leather are, the numerous joints in the belt, inability to stand wet, liability to injury by rats and insect pests, and when not taken care of the surface hardens, slips on the pulley, and cracks.

Rubber belts consist of layers of canvas bedded in, and faced with rubber; they stand wet, but, like all rubber compounds, are subject to deterioration in tropical countries.

On the whole the fibre belt is the most suitable for general use; it is made in one piece and is affected by neither water, heat, nor steam. The Balata type of belt gives satisfaction even under conditions precluding the use of leather.

The breaking strain of belts varies from 3,000 to 6,000 lbs. per square inch of sectional area, the sectional area being the width of the belt multiplied by its thickness, both in inches.

Four-ply Balata belting 6 in. wide (5.9 in. by. 27 in.) is a little over $1\frac{1}{2}$ sq. in. in sectional area and breaks at 4.65 tons, or $3\frac{1}{10}$ tons per square inch, equivalent to a driving strain of 1,765 lbs. per inch in width.

In practice, for a belt of this class, or its equivalent in double leather, 5 per cent. of this total strength would be taken as the working load. Thus the working load will be about 50 lbs. per inch of width for single leather or three-ply fibre, and 75 lbs. for double leather and the thicker fibre belts. These loads may be and often are exceeded, but such excess is not conducive to the life of the belt.

The power that can be transmitted with belting of any tensile strength varies directly as the speed and arc of contact with the pulley. The effective arc of contact is that of the smaller pulley of the pair and in no case can the arc exceed 180°, unless a tightening roller is used.

The useful effect transmitted by the belt is the difference in tension between its tight and loose sides, it increases directly with the speed, and is

highest when the belt travels over pulleys of equal diameter. The average speed of belts is 4,000 ft. a minute, 6,000 ft. is about the limit, as at higher speeds the centrifugal force, due to the weight of the belt itself, decreases the belt's grip on the pulley.

A safe rule is that 1 H.P. is transmitted for each inch in width of double leather or five-ply fibre belt running at 500 ft. a minute, and by each inch of single leather or three-ply fibre when running at 800 ft. a minute. Therefore to find the width of double belting required to transmit a given power at a given speed, multiply the horse-power by 500 and divide by the speed of the belt in feet per minute. For single belting, multiply by 800 and divide as before.

In laying out the work avoid vertical drives, and let the lower part of the belt always be the driving side; the upper part, being slack, will sag and increase the arc of contact.

The total length of belt for any drive is twice the distance between the shaft centres plus the semi-circumference of each pulley; when the pulleys are of equal, or nearly equal, diameters deduct half an inch in each ten feet for stretch. The ends should be cut perfectly square, so that when brought up butt to butt by the tightener the tension will be equal on each side.

The two ends may be joined by lapping them for a length equal to twice the width of the belt, and fastening with rivets, bolts, or laces. Alternative plans are—to butt the ends and place a lap piece over them, to unite the butted ends by plates or laces, or turn up the ends and use fasteners. Of these the first two plans are suitable for heavy drives, while the last cannot be used with a tightening pulley, nor when the belt is handled while in motion.

Laces are still used for joints passing under tightening pulleys; they should be wetted before use and worked double, the up and down laces passing in opposite directions through the same hole.

Joints made with plates last longer than laced ones, but plates should not be used under a tightening pulley, nor when there is considerable difference in the diameters of the driving and driven wheels.

Should the belt run towards one edge of the pulley, the cause may be unequal tension in opposite sides of the belt, or, as is generally the case, that the shafts are not parallel with each other.

Slipping of the belt is caused by slackness, too little width or arc of contact, want of adhesion, or insufficient speed for the power required. Chronic slipping shows that the belt, under the conditions of its use, is unequal to its work. These working conditions may be improved by substituting a perforated or a wooden pulley, or one covered with canvas, leather, or paper; these coverings increase the adhesion of the belt to its pulley. A radical cure is to use larger pulleys, giving the belt a higher speed, or to use a wider belt with increased tension; increasing the width without altering the tension will effect no improvement. As a temporary

measure, two belts may be used, one working on the top of the other; the outer belt will then take part of the load, and by its tension increase the adhesion of the lower belt to the pulley.

Round gut belts, such as are used for driving governors and light machine tools, are joined by screwing the end tightly into the socket, allowing the end to project a sixteenth of an inch, and burning this part off with a heated rod or wire.

HORSE-POWER TRANSMITTED PER INCH OF WIDTH.

Speed in Feet per Minute.	Leather.		Balata.					
	Single.	Double.	3 Ply.	4 Ply.	5 Ply.	6 Ply.	7 Ply.	8 Ply.
500	0.75	1.3	0.6	0.9	1.3	1.8	1.8	2.1
750	1.1	1.8	0.9	1.3	1.8	2.2	2.7	3.1
1,000	1.5	2.25	1.2	1.8	2.4	3.0	3.6	4.2
1,250	1.9	3.0	1.5	2.2	3.0	3.7	4.5	5.3
1,500	2.2	3.25	1.8	2.7	3.6	4.5	5.4	6.3
1,750	2.6	3.75	2.1	3.1	4.2	5.3	6.3	7.4
2,000	3.0	4.25	2.4	3.6	4.8	6.0	7.2	8.4
2,250	3.4	4.75	2.7	4.0	5.4	6.8	8.1	9.5
2,500	3.75	5.5	3.0	4.5	6.0	7.5	9.1	10.6
2,750	4.1	6.0	3.3	4.9	6.6	8.3	10.0	11.6
3,000	4.5	6.5	3.6	5.4	7.2	9.1	10.9	12.7
3,250	4.75	7.25	3.9	5.9	7.8	9.8	11.8	13.7
3,500	4.9	8.0	4.2	6.3	8.4	10.6	12.7	14.8
3,750	5.0	8.5	4.5	6.8	9.0	11.3	13.6	15.9
4,000	5.1	8.75	4.8	7.2	9.7	12.0	14.5	16.9
5,000	5.5	10.0	6.0	9.0	12.0	15.0	18.2	21.0

Ropes.

Cotton Ropes are used only for main drives and to transmit power from the motor to the shafting when the latter is required to run at a different speed. They are run at from 3,000 to 6,000 ft. a minute, and are stronger than belts, a good cotton rope having a breaking strain of 4 tons per square inch of area and a safe working strain of 250 lbs. Each rope is spliced at the ends, forming a complete belt, and works in grooves turned to receive it in the pulley face. The sides of these grooves slope at an angle of 40° to 45°, and the adhesion of the rope to the pulley is largely due to its wedging in the V grooves. The splices must be carefully made, as the rope will not run smoothly if thicker at one part than another.

Wire Ropes.—The average length of a good belt or rope drive is from four to six times the diameter of the largest pulley employed, and if this is materially exceeded, trouble is caused by the sag of the belt. There

is no such limit to the use of wire ropes, tensile strain and rotary motion may be conveyed for great distances, though in practice a mile s about the limit. Within this distance a well-designed rope drive will compare favourably with air or electricity, provided only transmission from point to point is considered, and not distribution at destination.

The flexible kinds of ropes are the most suitable, they are speeded at 2,000 ft. a minute, and require support at intervals according to their diameter, generally 120 ft. The driving and driven pulleys have V-shaped grooves, lined with wood or leather; for heavy strains at lower speed special pulleys are made with triggers in the rim, these triggers turn inwards and grip the rope when compressed by its passage around the rim.

The average life of the driving rope is from eighteen months to two years. In testing a transmission plant in which 10 H.P. were sent 1,000 yards, the loss was found to be $1\frac{3}{4}$ H.P.; but when the distance was increased to 5,500 yards the loss became $4\frac{1}{2}$ H.P. When used for higher powers the loss per cent. is less, but for distances of more than a mile the loss increases at a higher rate than with either air or electricity.

POWER TRANSMITTED BY WIRE ROPES (ON V PULLEYS).

Diameter of Pulley.	Revolutions per Minute.	Diameter of Rope.	Horse-Power.
Feet.		Inches.	
6	80	$\frac{1}{2}$	12
6	120	$\frac{1}{2}$	18
8	120	$\frac{5}{8}$	36
9	100	$\frac{5}{8}$	55
9	140	$\frac{5}{8}$	75
11	100	$\frac{11}{16}$	100
12	120	$\frac{3}{4}$	155
13	120	$\frac{3}{4}$	190
15	120	$\frac{7}{8}$	300

Air and Electricity.

When the problem is one of conveying power in bulk from an available source to the works, or to a distributing centre, the choice practically lies between compressed air and electricity. In no case can transmission be effected without loss; the inertia and friction of the generators, the resistance in conductors, leakage and loss of heat, all demand their percentage of the total power applied.

As considerable capital outlay is involved, the whole question of power transmission is deferred until the mine is sufficiently proved to warrant the expense; the mines on the Kolar Gold-Field, for instance, were proved to the extent of twenty years of dividends before electric power was intro-

duced. Such mines are naturally already equipped with steam plant, and compressed air has the advantage of being applicable to the plant already installed; it is beneficial underground, easily stored in moderate quantities, and safe in use.

The fact is, compressed air would be more economical if it were more dangerous; the very safeguards necessary in dealing with electricity tend towards efficiency. The initial cost of the power generators is about the same in each case; the cost of conductors in favour of electricity, especially when a high voltage is used. Air pipes require special preparation of the track on which they are laid, and in rough country this is no inconsiderable addition to the cost.

The loss in transmission is rather less with electricity than with air; a careful test made on a small scale, only 50 H.P. being transmitted for 3 miles, showed a loss of 2.35 H.P. for electricity, and 3 H.P. when air was used.

As far as mining is concerned there seems to be a great future for air as a means of power transmission; in only a few instances has any advantage been taken of reheating before use (which alone makes a difference in efficiency of 20 to 25 per cent.), nor of transmission under the higher pressures which stage compression has rendered available.

The relative merits of air and electricity depend on the conditions peculiar to each case, the advantage of the latter medium being greater as the power and distance increase.

When one or two mines only are involved requiring from 500 to 800 H.P. (a proportion of which is to be used underground), and when the distance is only a few miles of favourable surface, the advantages of a high-pressure air system are worth serious attention. This is especially the case when the motive power is water, and ample cooling is available.

For larger installations, supplying power to groups of mines, electricity is indicated; and it may be stated as an axiom that the higher the voltage the less the prime cost of conductors. For instance, the conductors required to convey a current of 500 ampères at 500 volts a distance of 10 miles will weigh over 100 tons in copper alone, even allowing a loss of 25 per cent. in transmission; but the same power could be conveyed as an alternating current at 5,000 volts with only 5 tons of conductors.

The copper required for any given distance will be found to vary as the square of the voltage, hence the saving on the high tension system. The current may be generated at the tension required, or at a low tension, and transformed either by stepping up or boosters, the booster being less economical and generally used only on light average loads with increases of short periods.

With the facilities offered by electricity and compressed air, both in transmitting and distributing power, it is strange so little has been done on mines towards centralising the power supply. All the power required

might be much more economically generated at a central station, placed where fuel could be easily delivered and water available. It could be fitted with mechanical stokers, filters, feed heaters, superheaters, and all the essentials to economic production of power, which could not be distributed to every isolated generator throughout the property. In fact, such an arrangement would do away with the small generator, working at low efficiency and requiring considerable skilled labour both in working and maintenance.

The reason that nothing of this sort is attempted probably is, that each successful mine passes through the different stages of exploration, development, and production, and is more or less separately equipped for each stage; and it is not considered prudent to instal permanent plant until the future of the mine is assured. The system suggested is not intended to apply to well-developed fields, where the mines have passed through this stage and the work has been gradually concentrated at certain points; but new fields and districts are constantly being opened up, and in each mine the earlier operations extend over a considerable length of the reef.

Every point of attack must either depend on manual labour or have a little plant of its own for hoisting, and possibly for pumping; in such cases, surely the compressor should be the first thing erected. The saving in fuel and attendance alone would be considerable, and power is made available at any part of the property by merely laying a pipe. As development proceeds additional compressor units could be added, or electric distribution installed before the permanent plant is fixed, the compressors being then relegated to the underground work.

The following particulars give some idea of power transmission services already in use, the data referring to the North Star Mine being extracted from the *Proceedings of the Institute of Mining and Metallurgy*.

At the North Star Mine the power generator is a Pelton wheel, 18½ ft. in diameter, operated by 240 cub. ft. of water per minute, under a pressure of 310 lbs. per square inch; at this pressure the velocity of the jet is 12,736 ft. a minute, and the discharge 88 cub. ft. per square inch of jet area.

The wheel runs at 110 revolutions a minute, and is directly connected to a compound duplex tandem compressor, having 18-in. low-pressure cylinders delivering the air at 25 lbs. pressure to the 10-in. high-pressure cylinders, the latter delivering the air at a working pressure of 90 lbs. per square inch.

In its passage between the high and low pressure cylinders the air traverses an intercooler consisting of forty-nine copper pipes, each 1 in. in diameter, and affording 230 sq. ft. of surface cooled by the waste water from the wheel.

The air mains are 6 in. in diameter, and the air is heated before use to a temperature of 300° Fahr. in a heater which burns a cord of wood a day, and has 395 square feet of heating surface; the pipes leading from the

heater to the winding engine and mine pumps are well covered with non-conducting composition.

With a jet $2\frac{3}{4}$ square inches in area, and passing 240 cub. ft. of water a minute, the theoretical H.P. is 327; of this amount the wheel yielded 293 H.P., equal to 88 per cent. of the total power applied. The compressor, delivering 192.5 cub. ft. of air a minute at 90 lbs., indicated 271 H.P., or an efficiency of 90 per cent. of the power applied.

Subsequent alterations to the nozzle resulted in 304 H.P. being obtained from 220 cub. ft. of water with a fall of 730 ft., or a generator efficiency of 90 per cent.; the compressor indicating 250 H.P., or 82 per cent. of the power it received.

Out of 300 H.P. generated, it was found that 200 H.P., or 66 per cent., were represented in work done in the winding engine and pumps.

The following particulars of a transmission plant erected by the Ingersoll-Sergeant Company contain some interesting references to those minor arrangements on which the efficiency of a plant so largely depends. The boiler-house, 39 ft. by $69\frac{1}{2}$ ft., contains three water-tube boilers of 250 H.P. each; mechanical stokers are used and the chimney dispensed with, draught being obtained by a 90-in. fan driven by an engine automatically regulated by the steam pressure.

The engine-house is 63 ft. by 69 ft., and the floor stands 9 ft. above the boiler floor, all the condensers and intercoolers being located in the basement.

The treatment of the feed water is worthy of notice, as it contained 12 grains of solid matter to the gallon. The feed was first settled in a tank containing three-quarters of a million gallons, and given a preliminary warming by the exhaust from the air pumps and other auxiliary engines, then raised to a temperature of 212° Fahr. in a heater, and finally brought to boiler temperature in a third heater. Treated in this way the water forms no scale in the boilers. In dealing with this subject in the chapter on fuel and feed, it has already been pointed out how closely allied are heating and purifying, and in fact, that heating includes purification.

The compressors are a pair of cross compound condensing two-stage Corliss engines, making 90 revolutions a minute. The steam pressure is 180 lbs., the high-pressure cylinders 20 in., and the low-pressure 44 in. in diameter, the stroke being 4 ft. The air cylinders are $24\frac{1}{4}$ and $39\frac{1}{4}$ in. diameter, and deliver 6,000 cub. ft. of *free* air per minute compressed to 100 lbs. per square inch.

Before entering the low-pressure cylinders the air is washed and cooled by being drawn through an arrangement of six hundred tubes with their lower ends dipping 2 in. below the surface of the water. The air is again cooled during its passage between the cylinders, and reheated to 300° Fahr. before use. Special stoves are used for the heating, but in some

parts of the distribution scheme the boilers, no longer required, are made to do duty as heaters by keeping a small coke fire on a portion of the grate.

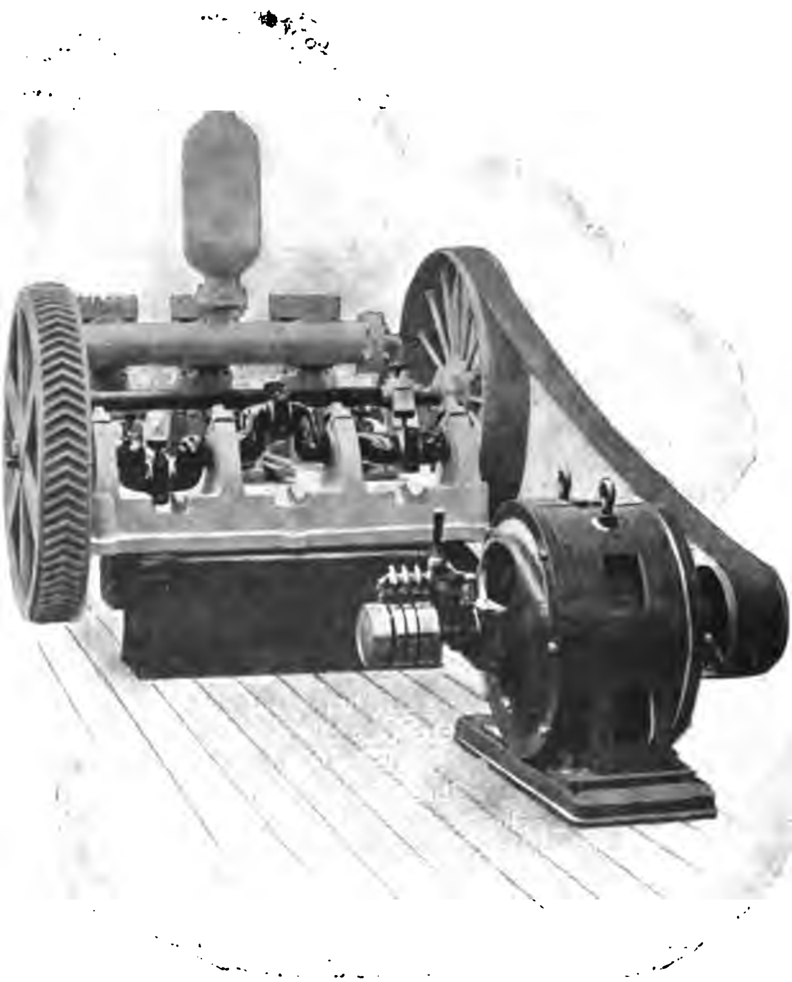


FIG. 80.—Three-ram Electrically-driven Pump.

The air mains vary from 8 to 12 in. in diameter, and are similar to those used in oil work, being about 25 per cent. cheaper than ordinary piping; under test these mains retained their pressure for twelve hours.

The whole installation has dispensed with forty-nine steam boilers with

an aggregate of 1,800 H.P., and shows a clear saving of ten thousand pounds a year in fuel and attendance.

One of the longest electric transmission schemes ever arranged was that from the Neckar Falls to Frankfort, a distance of 112 miles. At the Falls a 300 H.P. dynamo generated a three-phase alternating current of 1,490 ampères at 50 volts. This was then transformed to 30,000 volts, and transmitted over three naked copper wires, each 4 mm. in diameter. On arrival at Frankfort the current was again transformed by the step-down process to 100 volts.

Out of 80,500 watts transmitted in this way 58,000 were received, an efficiency of 72 per cent. in transmission, this remarkably good result being in some measure due to the form of oil insulator adopted. In other transmissions of not much more than a tenth of this distance the loss has been as high as 17½ per cent. The loss in transmission from point to point is largely a matter of initial outlay; the larger the conductors and more perfect the insulation the less the loss will be.

In a transmission scheme for mining purposes in Wales, a 300 H.P. Pelton wheel operates two direct current dynamos generating 170 ampères at 500 volts. The installation is remarkable for the way in which the current is governed by an automatic reversible booster, which admits current to, or supplies it from, a battery of accumulators. When the current generated is more than is required, the excess is diverted automatically to the accumulators, which in turn give out current when the demand exceeds the supply.

At another mining installation water wheels of 375 H.P., working under 860 ft. of water, operate a 250 kilowatt dynamo generating a three-phase alternating current of 2,750 volts. In this instance the distance is about a mile, and the loss stated to be only 2 per cent. of the force transmitted.

Those interested in this branch of the subject may with advantage consult "Electricity as Applied to Mining," by Messrs Lupton, Parr, and Perkin.*

* London: Crosby Lockwood & Son.

CHAPTER XIV.

TRANSPORT.

Tram Lines—Rails—Sleepers—Laying Track—Points—Turntables—Trucks—Light Railways—Locomotives—Ropeways, Various Systems—Telpherage—Mono-rails—Belt Conveyors—Elevators.

A LARGE proportion of the work in mining operations consists in moving and transporting weights, and the methods adopted for this purpose and the details of the equipment demand special attention, as a saving of even a fraction of a penny per ton amounts to a considerable sum on the tonnage handled during a year. Most of this weight passes over tram lines, which will often be found badly laid, poorly supported, and composed of rails too light for the working conditions, these defects being, if anything, more noticeable below ground than on surface. Whatever gauge be adopted it should be uniform above and below ground, the same rails and fittings employed throughout; both rails and trucks are then suitable for service at any point. A fairly wide gauge is necessary to ensure stability to the moving load, and to lessen the height of the trucks for any given capacity. As a rule an 18 or 20 in. gauge is adopted.

The rails used throughout the mine should be uniform in section and weight, 12 and 14 lbs. per yard being serviceable sizes for general use. A ton of lighter rails reaches farther, but the saving is not as great as it appears, as more sleepers will be required, and it must be remembered that the weight a rail will carry when supported by a firm ballasted track is no criterion of its capacity when laid on soft ground, or supported at irregular intervals. For light locomotive work the 20-lb. rail is the lightest that will be satisfactory, unless the ground is particularly firm or the track well ballasted.

The fish-plates are usually altogether too flimsy, some patterns being nearly cut in two by the bolt holes. They should be wide enough to bear firmly on the upper and lower rail flanges, and be secured by either square or oval necked bolts.

Sleepers.—Wood is generally used for this purpose, and, owing to its elasticity, it is perhaps the best material for roughly laid tracks. As a rule

ample sectional area is allowed, but the length is often deficient, and a considerable area of support on the outside of the rail is essential, especially when the ballast is inadequate. For a 20-in. track the sleepers should average 3 in. thick by 4½ in. wide, and not less than 3 ft. long.

The rails are secured to the sleepers by dog spikes; and as much of the rail laying is for temporary purposes the dogs should have ears at the back, so that they can easily be withdrawn by using a crowbar. When hardwood sleepers are used, holes must be bored to receive the spikes, the diameter of the hole being equal to the side measurement of the spike. No danger from white ants need be apprehended if the line is in frequent use.

Steel sleepers are made in many forms, both rolled and pressed. The ordinary rolled trough-shaped sleeper is secured to the rail by a bolt passed from beneath it; such an attachment is difficult to renew. The trough-shaped sleeper, being open at each end, has no hold on the ground, and the line is easily distorted on curves by the outward pressure of the load. Another form is rolled with a corrugation in which a hook bolt is placed to pull the rail against a clip. In this form the bolt may easily be

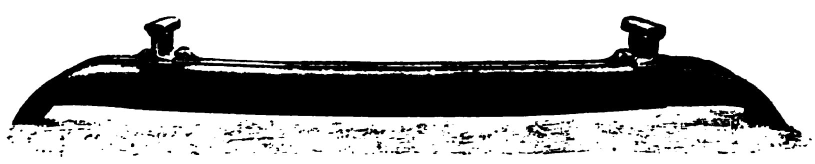


FIG. 81.—Pressed Steel Sleeper.

replaced, but the sleeper itself lacks rigidity and is easily deformed when supported only by soft ground. The rolled sleeper is quickly laid and may with advantage be used for temporary purposes and light loads. Additional length outside the rail is not so important in this case, as the sleeper lacks the necessary rigidity to convey the support to the rail.

The pressed sleeper (illustrated in Fig. 81), though more expensive, is free from all the above objections and suited to the heaviest tram service or light railway work. The pressed flanges ensure stiffness, the down curved ends hold the ballast and prevent distortion of the line on curves, its total length is double the rail gauge, and all screw fastenings are dispensed with, the rail being held by a simple key. About two thousand of these sleepers to the mile make an excellent road for light locomotive work.

Tram Lines.—Although the material supplied may not always be the most suitable, the fact remains that most of the defects in tram lines are due to imperfect laying of the track. It is considered "near enough" if the sleepers are so spaced as to prevent the rails from spreading suffici-

ently to let the truck drop through. The vertical deflection of the light rail is not considered, but possibly brought to the notice of the unfortunate trammer, compelled to push his load constantly uphill. The same individual also has to overcome the friction of wheels pressed against the axle boxes, owing to the two rails being at unequal heights. It is true the load is a light one, usually not more than 12 or 15 cwt., but the motive power is small in proportion.

It is evident, then, that a badly-laid track increases not only the labour of tramming, but also the wear of all rolling stock; in addition, work is

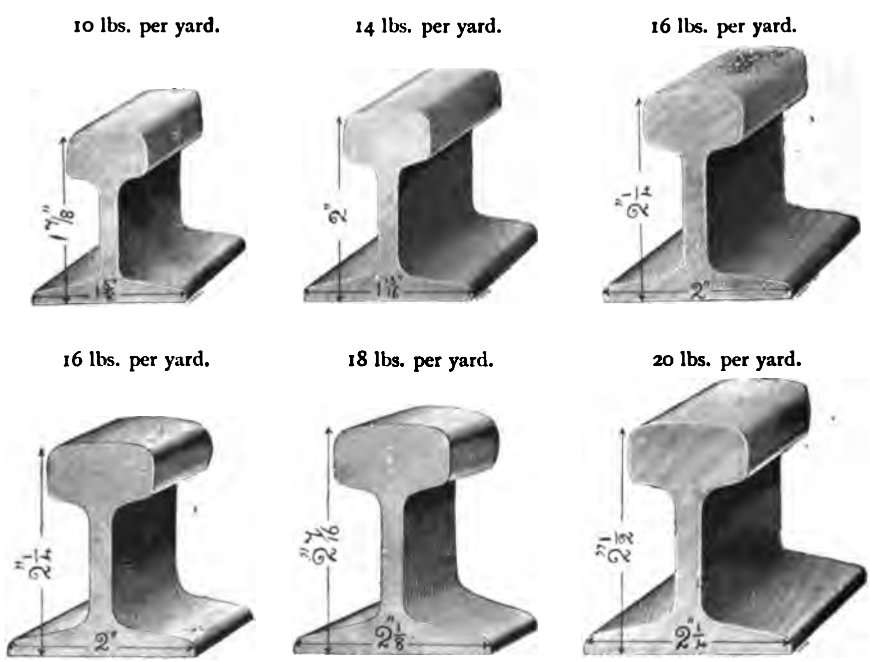


FIG. 82.—Standard Sections of Light Steel Rails. (Dick, Kerr, & Co.)

delayed by frequent derailments. All these things cost money, and a fraction of the total cost would have provided a good track in the first place.

To any workman of ordinary intelligence, it is as easy to lay a piece of track well as to do it badly, and the extra time required is of little moment. In preparing the road-bed, the ground may be roughly levelled with a spirit-level and staff, or by boning should the track be on an incline; the prepared surface should be covered with ballast if it can possibly be procured. Any ballast that affords free drainage for water lengthens the life of wooden sleepers besides increasing the strength of the track.

The sleepers are then spaced out about 2 to $2\frac{1}{2}$ ft. apart from centre to centre, and the rails spiked down to gauge, care being taken that the ends of the two rails are square with their length, or the sections will not join up properly. The different rail lengths are then fastened together with fish-plates and bolts, the track lined up for direction by slewing with crow-bars at the sides, and levelled up by packing ballast beneath the sleepers. If a section or two are checked with a spirit-level, the work may be carried on by the eye; a glance diagonally across the rail tops will detect any inequalities, and the level can be used at intervals as a check.

Each sleeper should be packed evenly, not for its entire length, but for 6 to 9 in. on each side of the rails. A sleeper that is insufficiently packed does not bear its share of the load and springs as the weight passes over it; water collects beneath it, and more packing is worked out by the splashing of the water, until the sleeper only adds to the weight on the rail.

Any attempt at slewing a piece of straight track around a curve only results in injury to the rail fastenings; a gradual change of direction may be made in this way if the radius permits, but for short curves the rails should be bent with a jim-crow. This tool is applied at equal distances along the length of the rail, the distance and amount of deflection depending on the radius of the curve. To allow play for the wheels, the gauge on curves is always kept slack; some of the rolled steel sleepers do not permit any change to be made, but if pressed ones are used, the keys are driven outside the rails on straight track, and inside on curves. This arrangement allows the gauge to expand on curves by twice the thickness of the key. A slight superelevation of the outer rail eases the work of tramming around curves considerably. In light railway work the rule for finding this superelevation is as follows:—The gauge in feet multiplied by the square of the velocity in miles per hour divided by the radius of the curve in feet multiplied by 1.23 equals the superelevation of the outer rail in inches.

Points.—Points are of two kinds, one having the tapered rail, as used in ordinary railway work; in the other pattern one pair of rails is shifted and replaced by the other, a form still used on some of the main lines in the Western States; the former is smoother in action, the latter best adapted to rough usage, and less likely to get out of order. In laying out points, the curve should be an easy one, an extra length of rail being placed between the point and crossing if necessary. Guard rails will be required at the crossing, and the point lever should be fitted with a balance weight to ensure that the points are either open or shut. Sleepers of additional length will be necessary to carry both lines of rails until their divergence is sufficient to permit the use of ordinary lengths.

Turntables.—When the space available is insufficient for a curve,

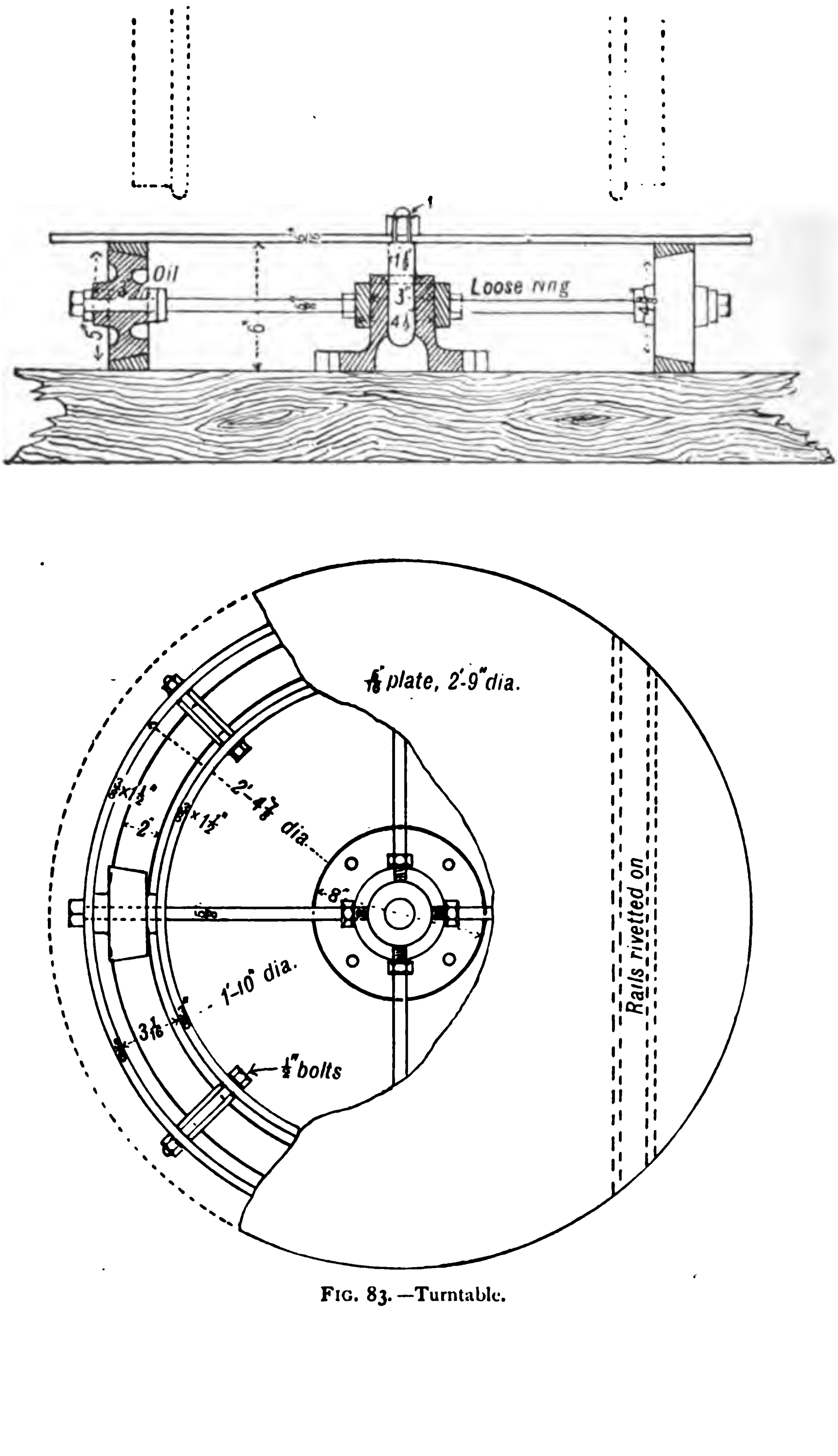


FIG. 83.—Turntable.

the direction of the road may be changed, or two tracks joined, by a turntable. In the patterns usually made for narrow tracks the weight is carried on the centre pivot; this necessitates clearance around the outer edge of the table, and allows it to dip as the load is moved; an even junction at the rail ends is therefore impossible.

A satisfactory table can be made from the particulars given in Fig. 83; the tapered circular rails on which the wheels run can be bent from grizzly bars, and the remaining materials will be found on every mine.

The table should be fixed on bearers or supported on a timber frame. Flat sheets are preferable for underground work, their surfaces being either greased or kept wet; the rail ends, where they join the sheet, are tapered down and splayed outwards, so as to guide the truck wheels within the track.

Trucks.—The ordinary mine truck is of 10 cub. ft. capacity, and holds half a ton, or of 15 cub. ft. and holds three-quarters of a ton. In either case the height must be reduced as much as possible, both for the sake of stability on the track and convenience in filling from chutes and faces; it must also be light and strong, must tip cleanly, and not be easily derailed. As a rule, these conditions are more completely fulfilled in those made at the mine than in imported ones, and the design shown in Fig. 84 will be found to give satisfaction.

The body is built of steel plates, either $\frac{1}{8}$ or $\frac{3}{32}$ in. in thickness, the bottom being of $\frac{1}{4}$-in. plate; if made of wood, the sides will be $1\frac{1}{2}$ or 2 in. thick, and greater over-all dimensions required for a given capacity; even in steel trucks the bottom is often protected by a renewable timber lining, as illustrated.

The sides project over the wheels, the increased width permitting the height to be reduced; the top edges are stiffened by a flat bar riveted all around, this method of strengthening being more amenable to repair than when the plates are rolled over a round bar.

Most mine trucks are of the end tip variety, the tipping angle depending on the height of the body from the rails and the position of the front axle; the closer the front axle to the front of the truck the better the angle, but the greater the weight to be lifted in tipping. The truck shown gives a particularly clean tip, and discharges well even when the contents are wet. The catches securing the door are worked from behind, and side handles are provided for guiding the truck around curves, and slewing it on flat sheets. Buffers and draw-hooks are not needed, as each truck is handled singly; the wheels, axles, and bearings are all interchangeable.

There is no doubt that on rough tracks and sharp curves the loose wheel works with less friction than the fixed, but the ordinary method of securing it to the axle is faulty, as grit and dirt are allowed to enter the axle box each time the truck is filled. This does not happen with the

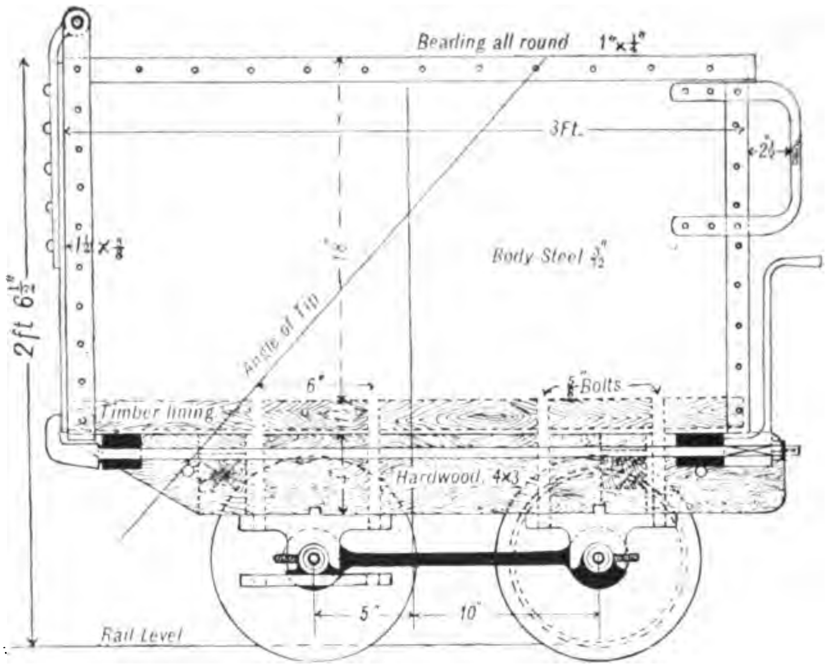


FIG. 84.—Mine Truck. Side View.

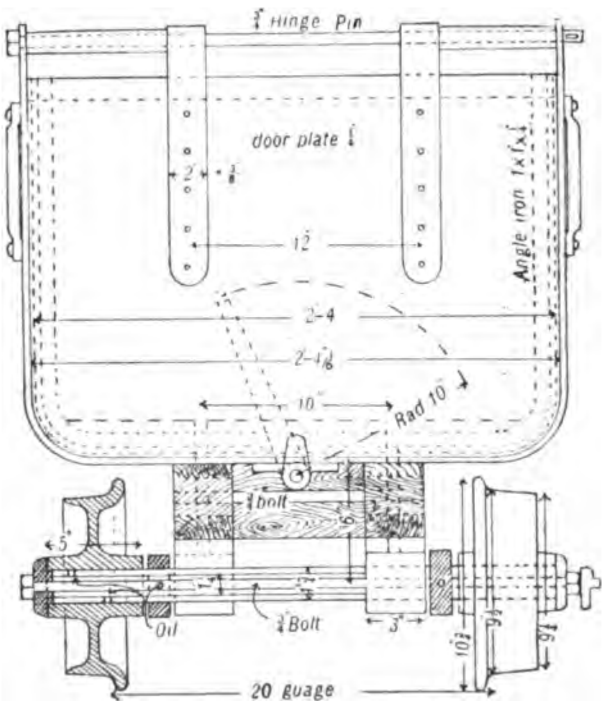


FIG. 85.—Mine Truck. End View.

solid boss wheel as used in U.S.A.; in Fig. 85 the wheels are protected by the overhang of the body. Steel wheels are lighter, and the disc pattern collects less dirt than the spoked variety; the tread should be tapered and joined to the flange by a full curve; a square flange joined to the tread by a narrow corner causes the wheel to mount the outer rail on curves. In this particular truck the axles are formed of hydraulic tubing, $1\frac{3}{4}$ in. outside diameter, holding a week's supply of lubricant for the wheels; as the back axle is not rigidly connected to the frame in a vertical direction, it is free to accommodate itself to the inequalities of the track.

The hinge pin of the door is interchangeable with the bolts holding the wheels and the axles together; a well-braced frame is placed between the axles and the body, so that the former shall be parallel to each other and square with the body, in spite of rough handling and bad treatment.

Fig. 84 does not make it quite clear that the distance pieces for spacing the axles are kept in position by a set screw through each boss.

Light Railways are used on many properties for transporting supplies, ore, and fuel; also for connecting the works with other transport systems, such as main lines and waterways. To keep the earthwork within reasonable limits it is generally desirable to follow the contour of the ground; a preliminary survey will decide the difference in levels of the terminal stations, and give a rough idea of the direction to be followed. The data obtained in the cross sections and contours will enable the line to be pegged out to best advantage, the cuttings being roughly equalled with the fillings, and the inclines kept within the limits determined on. As a general rule it may be said that an inclination of 1 in 40 is about the limit for useful traction, either by light locomotive or animal power.

In tropical countries drainage demands particular care, and means must be provided for dealing with heavy downpours, as well as preventing accumulation of water along the line, as this, if allowed to take place, causes settlement of the earthwork and displacement of the rails.

For light locomotive work a gauge of not less than 2 ft. is desirable, though gauges of 18, 20, and 22 in. are often used; the rails should not be less than 20 lbs. to the yard; and about 2,000 sleepers to the mile should be provided. As the line frequently proves of more use than was anticipated, it is advisable to provide, at the first, turn-outs where traffic coming in opposite directions may pass.

Light locomotives are made with cylinders 4 by 8 in., and 5 by 10 in., weighing about $4\frac{1}{2}$ and 5 tons respectively; provided with a leading bogie or radial axle, such engines can get around curves of 40 ft. radius, though nothing less than a chain radius should be allowed where space permits. On an incline of 1 in 40 these small engines haul about their own weight. The radial type of valve gear, although more exposed to injury, will be found more convenient and accessible than eccentric gear placed within

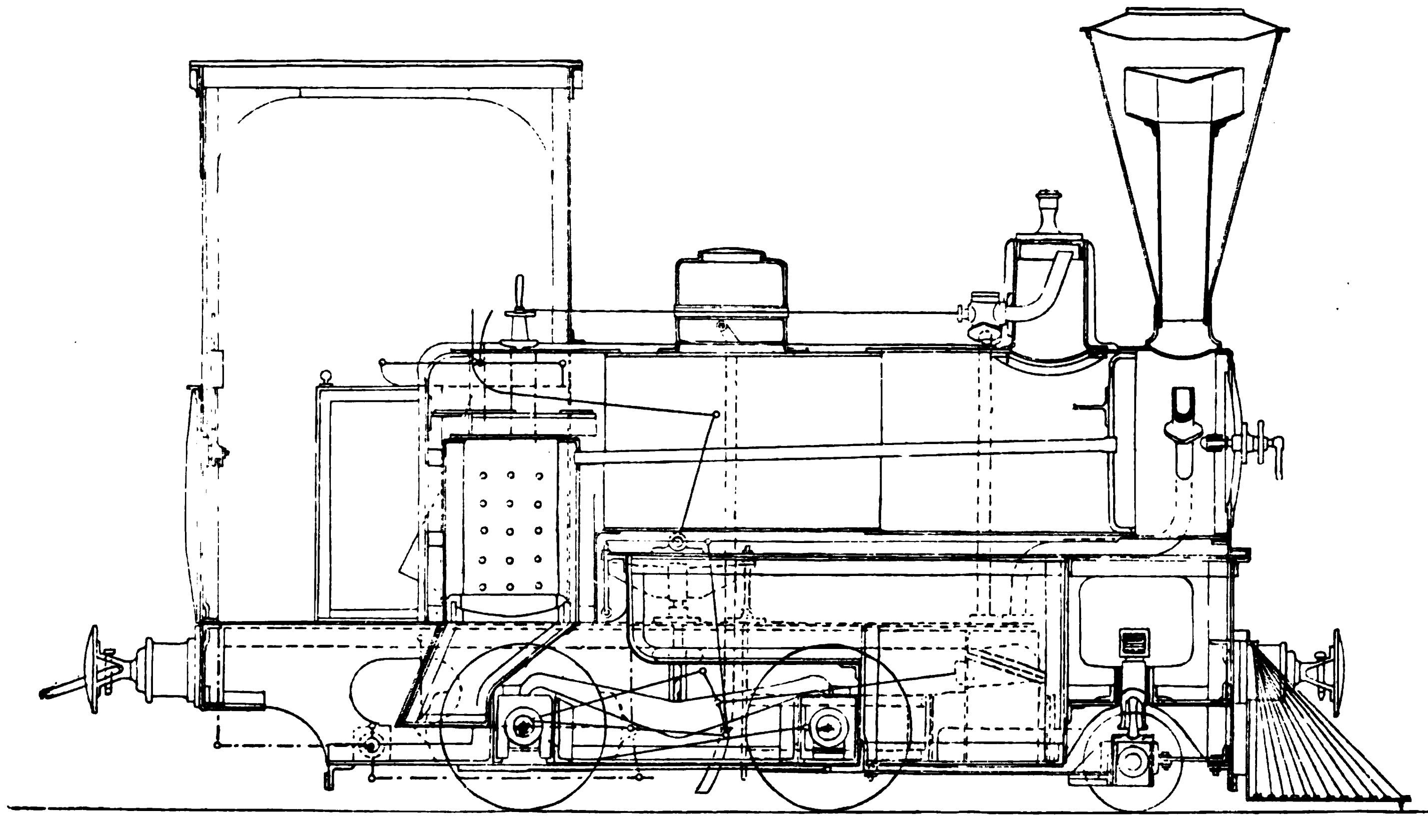


Fig. 86.—General Arrangement of Light Locomotive.

the frames. A horizontal baulk of timber, bolted across each end of the frame by the cow-catchers, is useful in supporting the weight of the engine should it run off the line.

Traction with engines charged with air at high pressure has not been successful; electricity, on the other hand, is a valuable medium for the purpose, and is employed in engines of many hundred horse-power in as low a potential as 220 volts. It is probably on account of the irregularity of the workings that mechanical traction and haulage are so little used in metalliferous mines.

The rolling stock will comprise trucks and waggons of different patterns, with central couplings and buffers, a brake to each vehicle and a spring over each axle bearing. Allowing £500 a mile for earthwork and grading, a light line with locomotive, trucks, points, sheds, feed tanks, and cleaning pit, will cost about £2,000 a mile; the estimate being necessarily a rough one, so much depending on the cost of transport to the mine.

Wire Ropeways.—Opinions are by no means unanimous as to the relative merits of ropeways *versus* tramways; on some mines the former give every satisfaction, while elsewhere they are condemned and endeavours made to replace them with tram lines. Ropeways work well when properly erected, when designed for the work to be done, and the particular conditions of service; they have the advantage of being applicable to rough country and gradients precluding the use of other means.

No particular pattern of ropeway is suited to all-round service, several styles and types are made, each being applicable to some ruling condition of load, incline, and span. A careful study of these conditions must be made before any decision is arrived at, and having collected all the data, it is well to be guided by the advice of some experienced manufacturer. Generally speaking, the direction should be chosen with greater attention to horizontal deviation than vertical deflection, as curves increase both the prime and the working cost. In every case the load to be carried is suspended from an overhead rope; this may be in motion or at rest, in the latter case the load is moved by a second rope.

The simplest of all systems is a single rope placed on an incline, with carriers running freely on it; such an arrangement being only possible when the loading station is above the point of delivery. A ½-in. rope, stretched in this way by a simple capstan or winch, will carry loads up to 1 cwt. on spans up to 1,000 yds., the incline being 6 ft. in 100. Such a system provides a ready means for transport of ore and fuel, especially in hilly country.

For general mining use, for conveying fuel, ore, sand, and residues, an endless running rope may be used, with carriers resting on it, but held by frictional contact only; each carrier can then be readily stopped for loading and unloading. But this system is suitable only for light loads

not exceeding 6 cwt., for spans not exceeding 600 ft., for inclines of not more than 1 in 3, and for tonnages of not more than 50 tons an hour. These conditions, however, cover all usual mining requirements. At one end of the line the rope passes around a drum connected with the motive power and brake gear, at the opposite end around a similar drum controlled by the tightening gear, intermediate support being afforded by posts and piers placed about 200 ft. apart. The carrier is suspended by a curved hanger from the carriage, which is fitted with vee blocks resting on the rope, these blocks being lined to afford additional frictional hold.

Two small wheels project from the carriage and engage with rails at the terminal stations; these rails, being slightly inclined, raise the vee saddles from the rope and disengage the carrier.

The load is contained in dumping buckets filled from bins fitted with swinging chutes acting as doors, the loading therefore causes little delay, a constant succession of empty carriers being received, and full ones despatched.

The approximate cost of a mile of straight line on this system would be £1,250, exclusive of power, posts, freight, and erection. The speed of the rope and load would be four miles an hour, and the cost of carriage from two to four pence per ton mile, the cost of fuel being additional. The figures in this section, and much of the information, are kindly supplied by Messrs Bullivant & Co., Ltd. In comparing the prime cost of rope and tramways, allowance must be made for difference in cost of erection; the earthwork, in the case of the ropeway, being confined to the terminal stations and post holes.

In a variation of this system the carriers are permanently fixed to the rope, the total weight carried is then evenly distributed, and can be taken up any incline; but the carriers cannot be stopped for loading without stopping the entire circuit, and the arrangement is less applicable to handling ores, sands, and loose materials.

The pattern in which the main ropes are fixtures and used as suspended rails is applicable to a greater load unit and wider spans; it is used when the loads, tonnage, spans, and inclines exceed the capacity of the types already mentioned. These main ropes are anchored at one end of the line, tightened at the other, and supported between these points at intervals of about 300 ft. The carriers are hauled at speeds of four to six miles an hour by a moving rope, and are attached to the running rope by clips, which automatically disengage on reaching the discharging point or terminal station.

The price cost of a mile of this ropeway carrying 10 tons an hour, in loads of 4 cwt., spans not exceeding 350 ft., inclines not more than 1 in 10, will be about £1,330; any increase in span or incline adding slightly to the cost. This form is used when the inclines are too steep for mere frictional contact, and can be arranged for spans up to 1,200 ft., 350 ft. being a limit more of cost than of width.

Modifications of this system are adapted for spans up to a mile in length, for loads up to 4 tons, and inclines of 40° and 45°; in such cases the load is taken by one carrier, running to and fro on the same rope, or returning on a parallel one.

The main rope is connected with the anchorage chains by blocks and falls, which serve not only to tighten the rope, but to take up any stretch that may occur.

The anchorage consists of a horizontal bearer sunk in the ground and supported by headers placed in front of it to distribute the weight; anchorages for spans of unusual length being made by iron girders embedded in concrete. The motive power may be steam or water; the amount required depends mostly on the inclines, very little being required for a level track. When the discharging point is below the loading station the descending load will suffice to pull the empty carriers up, and in this case the descent of the loads is regulated by brakes. The tonnages and spans mentioned in this section must not be taken in any way as limits, they merely form a basis for arriving at some idea of the cost per mile; a delivery of forty tons an hour can easily be arranged for and the lines duplicated to any extent. As instancing what can be done with a light ropeway, one span of 1,000 yds. is in use, the standing rope being $\frac{3}{4}$ in. and the running one $\frac{1}{4}$ in. in diameter. Eight loads of 1 cwt. each are carried at a speed of a quarter of a mile a minute.

According to its arrangement, the ropeway offers a quick service of light loads, or fewer loads of greater weight; it is applicable to situations where the gradients are too severe for tram lines or light railways, and is a means of hoisting and conveying in one motion, as required in the disposal of tailings or residues.

Telpherage is electrical traction, and is an automatic process in so far that each load has its own motor and is not accompanied by a driver. The load may be carried on rails, but is usually conveyed in a carrier having two grooved wheels running on an overhead wire rope; these wheels being driven by a motor taking current from a wire above them. The current, which is usually a direct one, is supplied separately to different lengths or sections of the conductor, each section being controlled by a switch; by movement of the switches the operator is able to stop or start the carrier in any section. By introducing resistances the speed can be reduced in going around curves, and on reaching its destination the carrier automatically switches off its own current and comes to a standstill.

As a rule each line forms a complete loop or circuit, the carriers moving only in one direction; the carrying rope is supported at intervals of about 100 ft., the distance depending on the load. The attachment of the rope to the supports allows free passage of the carrier arms, and as

the weight is entirely below the point of suspension, the wheels have no tendency to leave the rope. The objection to this system of conveyance lies in the skilled attention required by the many motors and other electrical details.

The Mono-rail system consists, as the name implies, of a single rail, which is supported by steel bearing plates attached to it at intervals, these plates resting directly on the ground. The cost of track laying is reduced to a minimum, not only is no expense incurred in laying two rails to gauge and maintaining the gauge afterwards, but the surface of the ground requires scarcely any preparation. On any ordinary surface the bearing plates would simply rest on the ground; only in case of exceptionally steep slopes would the ground be levelled or prepared for them. The truck is supported on fore and aft bogies, the wheels being doubly flanged; the body of the truck is so arranged that the load may be equally divided on each side of the rail, and therefore balanced. When intended for manual labour a pole is fixed horizontally at the back of the truck, and as the leverage is considerable, a very slight pressure serves to complete the balance of the load. For animal traction a third wheel is added which runs on the ground by the side of the track; in either case the lower part of the truck is only just clear of the ground and remains at a convenient angle for loading when the handle is released.

Owing to the double bogies on the trucks the sharpest curves are readily negotiated; the long load base and numerous rail supports permit a light section of rail to be used, one that can easily be bent to follow contours without special appliances. The cost of laying has been given as low as twenty pounds per mile, and there is no doubt the system is suitable at all events for pioneer work and for feeding light railways; this is especially so when used for such temporary work as fuel collection, when the tracks have to be relaid at frequent intervals as the ground surrounding them is denuded of timber.

Belt Conveyors.—The belt conveyor is an excellent means for transporting a continuous load for short distances, and is largely used for linking up the mine shaft and mill, for distributing the ore to the different bins within the mill, and is also replacing the revolving sorting table. The wear and upkeep are light, the chief expense being in the original outlay, and it is mainly on account of the cost of the belt that its range of action is limited.

The belt is made of canvas faced with rubber, it suffers little from abrasion, is made without flanges, and caused to assume a trough shape by the rollers on which it works. An average belt would be from 20 in. to 24 in. wide, be formed of eight plies of canvas, would run from 200 to 300 ft. a minute, and convey 40 to 50 tons an hour.

When employed in distribution work, special adjustable arrangements are provided causing the belt to discharge its load at any required point. The two ends of the belt need not be at the same level; provided the material is fairly dry, an inclination of even 20° in no way interferes with the action.

Elevators are used for raising loads rather than transporting them; they are employed when the mill site has insufficient fall for an automatic process, and the ore has to be lifted to a higher level for further treatment. Raff wheels answer the same purpose, but occupy more room, as their diameter must always exceed the height of lift required. The ordinary elevator consists of an endless series of buckets which contain the material to be raised, and works over pulleys at the highest and lowest points of the lift; the material being in either a wet or a dry state. The different patterns vary in the means adopted to join these buckets into a revolving band; linked chain may be used for short lifts, but the wear is severe, owing to sand and grit working into the hinged joints.

A more usual plan is to fasten the buckets to ordinary belting; they are spaced from 12 to 18 in. apart, the total number depending on the height of the lift, tonnage to be handled, and strength of the belt. Each bucket is secured by two or more bolts, in a horizontal row near its lip, and passing through a strip of iron at the back of the belt. The speed of the belt is from 300 to 350 ft. a minute; if run at a higher rate it is difficult to get a clean discharge.

The wear and life of the elevator depend largely on the feed being properly delivered to, and taken by, the buckets as they pass around the lower pulley. If a proportion of the feed misses the buckets it accumulates in the boot, and has to be scooped out by the buckets; a process very destructive to fastenings, and the strain often tears the buckets from the belt.

This is less likely to occur when the buckets are fastened to the inside of the belt, in which case skeleton pulleys with openings in the rims to receive the buckets will be required; such pulleys must be overhung, or supported by arms on one side only. This type loads and discharges well, but the spacing of the buckets cannot be varied, as it must always agree with the openings in the pulleys.

It is sometimes difficult to receive the fall of wet pulp, such as the discharge from an elevator, as even old stone-breaker jaws are quickly worn through by the constant attrition. The best plan is to build a box below the point of discharge, so that the pulp will fall on that already bedded within the box; as the bedding is being constantly renewed it needs no attention and costs nothing for repairs.

CHAPTER XV.

PIPING AND JOINTS.

Kinds of Pipe—Table of Threads—Jointing—Steam Pipes, condensation in ; Loss of Pressure in—Water Pipes, capacity—Air Mains, leakage—Power Supply Pipe—Flanged Joints—Red Lead and Rust Joints.

THE higher classes of solid drawn tubing are little used in mining work, the pipes generally employed being either butt or lap welded. The latter is the stronger of these two varieties, though in each there are qualities varying from the flimsiest gas tubing to stout hydraulic pipe. When ordering it is usual to specify the bore and maximum pressure, rather than define in any way the thickness of metal of which they are to be made.

There are, however, two evils to guard against, the first being an introduction of both English and American pipes to the same property. These differ in the pitch of their screw threads, and not only are they not interchangeable, but each make requires a separate stock of fittings and connections. The objection does not apply with so much force when the piping forms part of a complete outfit, as in diamond drilling plant; but endless confusion arises from the general employment of two different kinds of pipe. When ordering pumps and other machinery of American manufacture it is advisable to specify for either English pipe threads or plain flanged connections.

Bore of Pipe.	Threads per Inch.		Average Weight per Foot.
	English.	American.	
Inches.			Lb.
$\frac{1}{8}$	28	27	0.24
$\frac{1}{4}$	19	18	0.42
$\frac{3}{8}$	19	18	0.56
$\frac{1}{2}$	14	14	0.85
$\frac{3}{4}$	14	14	1.12
1	11	$11\frac{1}{2}$	1.67
$1\frac{1}{4}$	11	$11\frac{1}{2}$	2.24
$1\frac{1}{2}$	11	$11\frac{1}{2}$	2.68
2	11	$11\frac{1}{2}$	3.61
$2\frac{1}{2}$	7.2	8	5.74

The second evil is the introduction to the mine of a number of unnecessary sizes of piping, each requiring a separate stock of fittings and attachments; the more remote the mine, the greater this inconvenience is felt. Such piping is seldom ordered from choice, the real offender being the manufacturer of machinery supplied from stock, and in many cases, especially with pumps, the machines are intended for mining work. When these sizes are once introduced to a mine, they remain until the plant requiring them is worn out or discarded. There is no weighty reason for a pump being fitted with a 1¼-in. steam or 1¾-in. exhaust pipe; such sizes as ¾, 1¼, 1¾, 2¼ and even 1½ and 2½ in. could very well be dispensed with. There would be a great saving in the stock of fittings required, not to mention the screwing gear, if only 1, 2, 3, and 4 in. pipe were allowed on the mine. It might occasionally happen that a pipe would be a trifle larger than the work necessitated, but this would usually be an error in the right direction.

In joining together lengths of screwed piping, the cleanness of the screw threads is an essential feature. Whether the lengths are new or have been used before, it is advisable to run an old pair of dies over their screwed ends to ensure a clean thread. The coupling should be removed, it is not necessarily pressure tight because tightly fixed to the pipe, and a tap be run in at each end sufficiently to clear out the screwed part; even new pipes are generally damaged and battered at the ends by the time they are delivered. A little time spent in ensuring the fit of the screwed parts will be amply compensated in the speed with which they can afterwards be connected. The pipe should be a fair fit in the coupling all the way in, not merely be tight for the last two threads when the shoulder is reached, as such joints always work slack with expansion and contraction. Another necessary precaution is to clean the bore of the pipes, since any sand or grit is eventually carried into the motors, and cuts and otherwise damages the valve gear. In one case three miles of piping had to be almost entirely relaid; inside were found sticks, ropes, chains, oxen yokes, corn sacks, and various other rubbish that had accumulated during transport. The pumps had been endeavouring for three weeks to force water through these obstructions.

If any jointing material is used on the screwed surfaces, it should be placed in the coupling for internal pressures, and on the pipes for external. White lead mixed with oil to a thin paint answers very well for permanent work, plain linseed oil for air pipes or temporary work. Red lead paste, such as is used for flanged joints, is not suitable for pipe work. If placed on the pipe threads it comes off as the pipe is screwed in, and if applied to the interior of the coupling it is compressed into a projecting collar which diminishes the area of the pipe, increases the friction, and is liable to break off with vibration and be carried into the motors.

When placing pipe lines in vertical shafts, the easiest method is to

fasten the rope to the lowest pipe and add the others at surface as the rope is lowered. In this way several hundred feet can be placed in position in an hour or two. The completed line will require staying every 40 or 50 ft.; in long lengths the weights also must be taken up at intervals. This is not an easy matter when the pipe contains steam and is subject to expansion; the simplest plan is to provide long springy bearers, reaching right across the compartment, and to tighten the clamps on the pipes while heated by the steam. Should the expansion be greater than the spring of the bearers can provide for, the pipes must be supported by springs. Expansion joints are not required, as the pipe is seldom rigidly connected at both ends.

In screwing together hydraulic pipes, not only must the threads be perfectly clean, but the screwing continued until the coupling feels distinctly warm to the hand.

Flanged joints are generally preferred for pipes exceeding 4 in. in diameter; the flanges may be fixed or loose, the latter, with a recess to hold the joint ring, being suitable for all purposes but long vertical lines. In laying pipes horizontally, it is necessary to retain the joint ring in position until held by the flanges. This is done by a few pellets of red lead, or a turn of string passed through the bolt holes. The opposing flanges should meet evenly, bolts will pull them together even if the line of pipe is considerably deflected, but a sound joint seldom results.

When deviation from the general direction is required, it is safest to make the joints first, and ease the pipe around afterwards, in the same way that straight rails can be brought around a curve of sufficient radius.

Steam Pipes.—Although the velocity with which steam at ordinary working pressures issues is about 800 ft. a second, when required for power purposes the speed should not exceed a tenth of this rate, or from 80 to 100 ft. a second. The condensation of steam in naked pipes is known to be considerable, yet how often the work of pipe laying is regarded as complete when once the connection is made, the covering with non-conducting composition being deferred for that opportunity that never arrives, in the hope that the loss is not so serious as it is stated to be. There is some justification for this hope when no figures as to the actual loss incurred are available; but carefully made tests show that under ordinary working conditions 10 ft. of naked steam pipe may mean an increased consumption of over 5 tons of coal a year. The loss incurred in hundreds of feet of such pipe is obvious, to say nothing of the extra wear on the internal parts of motors, due to condensed water and wet steam.

In 1,100 ft. of 7½-in. steam pipe connecting with an underground winding engine, the condensation was found to be 748 lbs. per hour, or equal to over a ton of coal a day, despite the fact that owing to difference in altitude

the pressure was 1 lb. higher at the engines than at surface—showing plainly that increase of pressure, when accompanied by decrease of temperature and volume, is no gain in the energy available.

In vertical shafts one of the best means of protecting the pipe against radiation is to enclose it within another, the latter being two or three inches greater in diameter. If the inner pipe is kept central at intervals and the annular space between the two pipes plugged at the top and bottom of the line, the dead air enclosed forms an excellent protection, while the outer pipe keeps the inner dry. Pipes laid horizontally are surrounded with any non-conducting material—felt, wool, hair, charcoal, and sawdust are all suitable; one of the simplest methods being to embed the pipe in a box launder filled with sawdust. For high pressures and superheated steam a substance that will not char is required; asbestos preparations and mineral wool answer the purpose. Should none of these things be at hand old ropes, straw, grass, clay, and even mud, are better than nothing. Under roof these rough coverings may be bound around with canvas, and further protected by coats of tar should the pipe extend beyond the roof.

The following table gives the weight of steam that may be passed at various pressures through pipes two hundred and forty times as long as their bore, with a loss not exceeding 1 lb. of effective pressure.

Gauge Pressure.	1-in. Pipe.	2-in. Pipe.	3-in. Pipe.	4-in. Pipe.	5-in. Pipe.	6-in. Pipe.
Lbs. per sq. in.	Steam lbs.	Steam lbs.	Steam lbs.	Steam lbs.	Steam lbs.	Steam lbs.
50	4.0	20.0	49.0	91	150	226
60	4.3	21.0	53.0	97	161	241
70	4.5	22.6	56.0	103	170	256
80	4.8	24.0	59.0	108	180	269
90	5.0	25.0	61.6	113	187	281
100	5.25	26.0	64.0	118	195	293
120	5.5	27.8	69.0	127	210	314
150	6.0	30.0	75.0	138	228	343

Water Pipes.—The friction of a fluid passing through a pipe varies with the length of the pipe, and as the square of the diameter; the velocity of the flow is due to pressure, and in case of the delivery of water under a constant head is found by multiplying by eight the square root of the head in feet. An increased delivery may be obtained either by increasing the pressure under which the water flows, or by retaining the same pressure and enlarging the bore of the pipe. Under equal heads the delivery of two pipes varies as the squares of their diameters, and doubling the diameter will increase the capacity four times. Practically the increase is greater, as friction is highest in contracted passages where the velocity is

necessarily augmented, and especially when these passages divert the direction of the flow, as is the case with tees, sharp elbows, and valves. Whether the pipe be the delivery main of a pump, or used for power purposes, the velocity of the water should not be higher than 360 ft. a minute, and when possible it should be limited to 240 ft., or 4 ft. a second. A pipe line of any diameter and length will pass a constant quantity of fluid under a given head; and a line of smaller diameter will require a greater head to produce the same result. The difference is an expenditure of power in overcoming friction, and may either cause increased load on the pump, or decreased power from the motor.

The following table gives the number of cubic feet of water per minute that may be passed through 100 ft. of pipe at varying speeds, and the loss in pressure incurred or increased pressure required.

Bore of Pipe.		Velocity of Water in Feet per Second.							
		2	2½	3	3½	4	4½	5	5½
Inches.									
4	Cub. ft. per min.	10.5	13.0	15.7	18.3	20.9	...	...	..
	Loss of head, feet	0.47	0.73	1.0	1.4	1.8	...	...	...
6	Cub. ft. per min.	23.5	29.4	35.3	41.2	47.1	53.0	58.9	70.7
	Loss of head, feet	0.29	0.45	0.65	0.88	1.16	1.47	1.8	2.6
8	Cub. ft. per min.	41.9	52.1	62.3	73.0	83.7	93.3	105.0	125.0
	Loss of head, feet	0.29	0.32	0.47	0.64	0.84	1.0	1.32	1.9
10	Cub. ft. per min.	65.4	81.8	98.2	115.0	131.0	147.0	163.0	196.0
	Loss of head, feet	0.16	0.25	0.37	0.5	0.65	0.83	1.0	1.47
12	Cub. ft. per min.	94.0	118.0	141.0	164.0	188.0	211.0	235.0	283.0
	Loss of head, feet	0.13	0.21	0.3	0.41	0.54	0.68	0.82	1.2
14	Cub. ft. per min.	128.0	160.0	192.0	224.0	256.0	288.0	321.0	385.0
	Loss of head, feet	0.12	0.17	0.25	0.34	0.44	0.56	0.7	1.0
16	Cub. ft. per min.	167.0	209.0	251.0	293.0	335.0	377.0	419.0	502.0
	Loss of head, feet	0.1	0.15	0.22	0.3	0.39	0.49	0.61	0.88
18	Cub. ft. per min.	212.0	265.0	318.0	371.0	424.0	477.0	530.0	636.0
	Loss of head, feet	0.08	0.13	0.19	0.26	0.34	0.44	0.54	0.78

Pump mains are often suspended, or lifted in long lengths, and the flanges must be of extra strength to stand this tensile strain; cast iron is still largely used in their construction, though wrought iron or steel make a lighter pipe, and save in cost of transport. This reduction in weight must not be carried to excess, as a flimsy pipe is unable to stand the vibration caused by the pulsating flow of water.

Air Pipes.—Pipes for conveying air under pressure require special care in laying, and the use of high-class fittings, to avoid leakage. The threads of screwed pipes should be thoroughly cleaned and wiped over with linseed oil; rubber rings for flanged joints may be soaked in hot water to soften them before screwing up the joint. The completed main, if pumped up and shut off, should hold its pressure until next day; should it not do so, the leaks must be found, as they never stop themselves by rusting up, as steam leaks often do. Locating numerous small leaks is as wearisome a task as can be undertaken, each leak may be inaudible, and invisible to the unaided eye; every joint must be tested by painting it around with soapsuds, and leaky ones tightened or caulked. When this test fails the line may be tested in the same way as a bicycle tube is tried, by immersing each joint in water; this can be done by tying canvas around the joint, filling with water, and looking for bubbles.

The worst leaks are usually in the connections of the hoses, and in the small temporary pipe laid as the work proceeds and headings advance. In laying out the main means must be provided at the lower end, and also in any depressions occurring in horizontal lengths, for draining the water that accumulates; while pipes conveying reheated air need as careful protection against radiation as those carrying steam.

Power Supply.—Pipe lines conveying water for power purposes are seldom of the same diameter throughout. The pressure varies from nothing to maximum, and a smaller area is sufficient under the greater pressure; this difference in diameter permits nesting for shipment. The pipes are made of steel sheets, rolled to shape and riveted, each plate making one complete section; the sections are united to form pipes of such lengths as can conveniently be handled, the thickness of the sheets being increased towards the lower end of the pipe line, where the pressure is highest.

English-made pipes are generally thicker and heavier than those made in America for equal pressure; in the latter country sheet steel $\frac{1}{16}$ in. thick is used in 11-in. pipes for pressure of 225 lbs., while a 30-in. pipe with a working pressure of 300 lbs. per square inch is made $\frac{5}{32}$ in. thick.

Double riveting secures the longitudinal seams when the pressure is higher than 100 lbs.; rivets of $\frac{1}{4}$ in. diameter and less may be headed cold, but hot riveting is preferable and less likely to crystallise the head of the rivet. Caulking is of little use when the sheets are $\frac{1}{8}$ in. or less in thickness, and as the riveted joint is never quite tight, all pipe lines leak at first; but the leakage ceases when the flow of water has carried through the line a few loads of sawdust, shredded moss, or horse dung.

As a protection against corrosion, and also to prevent leakage, each length of pipe is dipped in a bath of melted asphaltum. The bath may be

thinned by the addition of mineral oil, but a thick mixture is most effective in stopping leakage. The secret of obtaining a smooth coating is to allow each pipe to remain in the bath until heated to the same temperature as the mixture. The pipes need not necessarily be totally immersed, but may be turned at intervals in the bath until equally heated all over.

When the line is laid on easy curves permitting expansion and contraction, the completed pipes, when 18 in. or more in diameter, may be riveted together into one continuous length, but it is more usual to have some form of joint every 20 or 25 ft.

Spigot and faucet joints, if well made and caulked with lead, may be relied on for pressures of 250 lbs. The interior of the joint is first tightly packed with rope yarn, leaving an inch near the mouth to receive the lead. After running up the lead must be well caulked. In making this form of joint on pipes of 18 in. or more in bore, the clay luting may be unable to stand the pressure of the lead. In this case the joint may be run in sections, commencing at the lowest part, or a clamp may be fastened around the pipe to support the clay.

A simple form of joint consists in turning each end of the pipe outwards, so that it is slightly bell-mouthed, a loose collar is then slipped over the joint and caulked with lead; or caulking may be dispensed with, and two glands arranged to compress elastic packing in the space between the collar and the pipes.

The pipes may also be joined by driving the end of one within the other, tamping in a ring of rope yarn, and hammering down the rim of the outer pipe. Flanges of ordinary angle iron riveted to the ends of the pipes, and screwed up with rubber rings intervening, will stand pressure of over 200 lbs., provided the bolts are pitched closely. For conveying water when the pressure is inconsiderable, spigot and faucet joints may be caulked with rope yarn only, or filled up with Portland cement.

All caulked joints are liable to draw with the expansion and contraction of the pipes. This trouble may not arise if the line is constantly full of water, but if liable to be empty at times the line should be covered over, or buried in a ditch. When laid on the surface of the ground, the outside of all horizontal curves must be well banked up or anchored back, as, like the bent tube of the pressure gauge, the line endeavours to straighten itself when under pressure.

At the highest point of vertical bends escape valves are required to allow trapped air to pass out, and a sluice valve is placed at any considerable depression for clearing out stones or gravel that may be carried into the pipe.

A safety valve is often placed near the nozzle to protect the line from the shocks caused by sudden stoppage of the flow. The inertia of the moving water is considerable, and if the nozzle is choked, or the valve suddenly closed, very high pressures result. When the head of water is

not very great, the safety valve may be replaced by a stand pipe. Pipe lines made of thin sheets may be sufficiently strong for the bursting strain, but be unable to stand the external pressure caused if the gate at the intake be closed while the nozzle is still flowing. The line may be protected in this respect by spring-controlled safety valves opening inwards, at least one of them being near the intake. This precaution is hardly necessary in pipes of English manufacture, on account of the greater margin of strength.

Flanged Joints.—The thickness of the material used in making a joint depends on the accuracy of the facing, the thickness of the flanges, and the spacing of the bolts. The thinner the material the less the bursting strain on it and the better the joint. But thin substances can only be used when the flanges are accurately faced and the bolts pitched sufficiently close to prevent any spring between them. The most perfect form of joint is the meeting of two scraped or ground surfaces, which come into actual metallic contact without any intervening material. Such joints may be found in the cones of union pieces, the valve chests of some rock drills, in locomotive and other high-class work, but their cost prevents their general use.

For well-faced flanges, such as the covers of cylinders and valve chests, a ring of brown or cartridge paper soaked in boiled linseed oil makes a reliable joint, and one easily cleaned off when the cover is removed. Corrugated metal rings answer the purpose admirably for steam connections and boiler mountings. Lead and copper wire are also suitable, or rings may be cut from asbestos sheet, but they should be damped before being screwed up. A copper ring lapped with asbestos will stand the highest superheated steam temperatures.

Flat rings of rubber and insertion material are suitable for water and air connections, but become hard and brittle if exposed to high temperatures. If each face of the ring is rubbed with chalk or charcoal the same ring may be used several times, a convenience in joints that have to be frequently renewed. In dealing with high pressures the flat ring receives insufficient support from the flanges, and may be blown out unless held in a recess. It may then be used for pressures up to 800 and 1,000 lbs. with safety.

If leather rings are used care must be taken that they are well soaked before the joint is made, and that they are of uniform thickness throughout.

An increased thickness of material is required when the flanges are unfaced, or when their surfaces are corroded or uneven, and the thicker material must have greater strength to stand the bursting strain upon it. This is exemplified in the lapped ring in pit-work, originally used when the flanges of the pipes were unfaced. The joint material is a strip of blanketing or coarse flannel bound like a puttee around a central ring of flat iron, the ring affording the necessary support and preventing the joint from being blown out. Owing to the cheapness of machine work, pump joints are

always faced at the present time, and a rubber ring is sufficient; but the lapped joint is still largely used for doors, as the joint can be made many times with the same ring.

Formerly not even steam joints were always faced, and old Cornish pumping engines are still working in which the joint between the cylinder and valve boxes is 1½ in. thick, and formed of many layers of sheet lead caulked after being screwed up.

In all flanged joints the opposing faces should meet squarely, and the bolts diagonally opposite each other be tightened gradually, screwing with even strain on each bolt until the whole joint is tight. The use of excessively long spanners should be avoided, as leading to unnecessary and even dangerous strain on the bolts, nor should shifting spanners be used, as the tool suffers as well as the corners of the nuts.

All that is required to avoid leakage is a pressure-tight ring between the two flanges. This is secured when the jointing material is confined to the annular space between the bolt holes and the bore. Nothing is gained by extending the material to the edges of the flanges, any more than a valve would be made more steam-tight by widening its beat. On the contrary, there is the additional risk of leakage through the bolt holes, and the pressure of the bolts themselves is less effective, being distributed over a larger area.

The red lead joint, in spite of its messiness, becomes useful when other materials are not at hand, and also for situations exposed to both fire and water. The red and white lead, in equal proportions, are first ground together to a smooth paste, sufficient boiled oil being added to make a stiff putty. The flanges are wiped over with an oily rag, and afterwards with clean waste until almost dry, this being the only state in which the lead will adhere properly to the iron. The lead may be spread evenly over the flanges to the thickness of one thirty-second of an inch, or may be rolled into ropes and laid in one or more rings concentric with the bore. In either cases the screwing up must be even and gradual, as the soft material is easily squeezed out should the pressure be greater at one point than another.

All superfluous lead squeezed into the bore should be scraped out, as it decreases the area of the passage, interferes with the flow, and, if allowed to harden, may be detached and carried into the valve boxes of motors. All red lead joints require some time for setting or hardening, and pressure should not be applied until some hours after the joint is made. When once set it can only be broken by driving fine wedges between the flanges, and is not easily removed from the faces of the joint. It is therefore suitable for boiler mountings and other permanent work, and should not be used for joints that are frequently made, as man and mud hole doors. For the latter purpose a rubber ring answers very well, but will require further tightening after the boiler is hot, as warm water softens the rubber.

The rust joint is only used for absolutely permanent work, and is most satisfactory when caulked into a groove. It may be employed for spigot and faucet joints, for joining the plates of iron tanks, filling between bed-plates and cap stones, and other purposes. The cast-iron borings should be moistened with water containing about an ounce of sal-ammoniac to the quart. This mixture sets quickly and should be made as it is required. Powdered sulphur added to the mixture makes it set more slowly. If the joint is a large one it is divided into sections by folding wedges, each section being caulked in equal layers about half an inch thick. All joints made in this way must be kept free from oil, and when the borings have once set they can only be removed by chipping.

CHAPTER XVI.

CONSTRUCTION.

Foundations of Buildings—Mortar—Cement—Rubble Masonry—Brick Making and Laying—Concrete—Asphalt—Roofing—Roof Frames—Painting.

Foundations.—A good foundation is essential to the stability of every structure. It supports the weight, prevents unequal subsidence, damage by frost, and the undermining effect of water; the excavation is therefore carried down below the vegetable mould on the surface. On sloping ground the bottom of the trench does not follow the contour but is finished in a series of levels with intermediate steps between. In soft ground the footings may be extended to twice the width of the wall, and additional depth allowed, so that side friction relieves the bottom of a portion of the weight.

Mortar is a mixture of slaked lime and sand, usually one part by measure of lime to three and a half of sand. As a coarse mortar for bedding large stones, one part of lime may be added to four parts of gravelly sand. There are two kinds of lime, the hydraulic or blue lias, which sets anywhere, and the ordinary fat lime which does not set under water or even in damp positions. The sand should be clean and sharp grained; tailings are generally used, and answer very well. Sea sand makes a damp wall even when thoroughly washed in fresh water before use. The lime and sand must be thoroughly incorporated by turning the mass several times with shovels, better still if mixed in a mortar mill. It should be used when fresh, as by exposure to air the hydrate becomes a carbonate, or the mortar "sets."

Cement.—Good cement does not deteriorate with age if kept dry; as with mortar, the sand mixed with it must be clean and sharp grained, no more water should be added than is necessary to bring the mixture to the required consistency.

Cement is strongest when used alone, its strength being diminished in inverse proportion to the sand added. Thus two parts of sand reduce the strength to one-half, and four parts to one-quarter.

Cements vary in quality, but in every case the slower the setting the stronger will be the result. The best setting is under still water, and cemented floors are often flooded with water to the depth of half an inch until set. Both stones and bricks should be well soaked in water before being laid in cement.

Casks of ordinary Portland cement hold 5 cub. ft. and weigh $3\frac{3}{4}$ cwt., or six casks to the ton.

Rubble Masonry.—In work of this class the weak angles of each stone are knocked off, it is cleaned, wetted, and laid on its broadest side on a bed of mortar. The corner stones are roughly dressed and kept a course higher than the rest of the work for convenience in fixing the lines. Stretchers are those stones laid with their greatest length in the direction of the wall, and serve as longitudinal ties. Headers are placed transversely to bind the face to the body of the wall, or tie the two faces together. After the corner stones have been plumbed, the front and back faces of the wall are laid to lines stretched from corner to corner, and the centre of the course filled in and levelled up with chippings and fragments of stone bedded in mortar. With the kind of labour usually available, nothing is gained by reducing the width of the wall to less than 15 in. On 12-in. walls too much time is spent in cutting and trimming stone. In ashlar work the stones used in one course are all of the same height, and the upright joints strictly perpendicular. This is not necessary in rubble work, though care must be taken that the vertical joints in any course do not coincide with those in the course below.

Brickmaking.—As a rule the dump supplies all the building stone required, and plenty of this material is at hand. Still, there may be conditions rendering the use of bricks advisable. The clay for the purpose should be near at hand, and some care in its selection is necessary to ensure a good result. With too sandy a clay the bricks will be weak, while too rich a clay leads to shrinkage and distortion in burning. When a suitable sandy clay is found it should first be tempered by exposure to the weather and then mixed, either by treading or pugging in a mill. The ultimate strength of the brick depends largely on the thoroughness of the pugging and on the quantity of water added during the process being no more than will make a plastic mixture.

The moulds for hand-made bricks may hold two at a time, each being larger than the required size to allow for shrinkage in burning, the length of the brick being equal to twice its width plus the thickness of the mortar joint to be used (generally one-quarter of an inch).

Wear is prevented and a more uniform size of brick produced if the mould is fitted with a sheet-iron lining. When turned out of the mould

the newly-made bricks should not be exposed to the sun, but be allowed to dry slowly for a fortnight before being burned.

The simplest form of kiln is a dome-shaped erection with walls two bricks thick. The interior is filled with bricks loosely arranged so that the draught from the fire below can play around them. About two days' firing will be required for a stack of moderate dimensions holding, say, a hundred thousand bricks. The kiln should not be opened until it is cool, which will be at least a week after the firing has ceased. The bricks of which the outer walls are built may be turned around and again fired on a subsequent occasion. They will then serve for ordinary building purposes, though not equal to those in the interior of the kiln.

In **Bricklaying** it is most important that the bricks should be well soaked beforehand, otherwise, and especially in hot climates, they absorb the moisture from the mortar, causing it to dry too rapidly. In addition to keeping the various courses even, all the walls of a building should be kept about the same height during construction to ensure even settlement. Care must be taken to space the joints by the use of headers and stretchers so that a sound bond is obtained. This point requires particular attention at corners and where two walls join. A wall 9 in. or one brick thick is sufficient for a structure one story high; in two-story buildings the lower is one and a half brick thick. This may be increased to two bricks in stores and warehouses where considerable weight may accumulate on the upper floor.

Concrete is a mixture composed of cement or hydraulic lime with stones, gravel, and sand. The following proportions by measure are generally used:—

Lime.	Cement.	Sand.	Gravel.	Broken Stone.
1	1	2	2	3
1	...	2	4	...
...	1	1	...	5
...	1	...	...	6
...	1	...	4½	2½

The gravel and broken stone must be clean, the component parts well mixed in a dry state, wetted with a spray, and turned over at least three times. Each stone should then be covered with the mortar. It is advisable to let the concrete fall into its position from a height of a few feet, as ramming tends to work the cement to the surface, leaving a poor mixture below. Artificial stone blocks of any required size and shape can be produced by filling moulds with concrete, the inside of the mould being

well covered with grease or soap (a precaution ensuring a clean face to the finished block).

It is an excellent material for engine foundations, and the quantity required for any size block may be reduced by building "plums" into the heart of the mass. These large stones should be roughly dressed until their surfaces are clean, and be well bedded in the concrete, care being taken that no hollow spaces are left under or around them. The strain on the sides of the mould is severe when building a block large enough for an engine foundation. If building in a pit, the mould is strutted at close intervals from the banks; when the structure is above the surface of the ground, sloping shores are not always to be relied on, and any spring in the planking results in bulges in the finished block. One way of getting over the difficulty is by introducing through bolts to hold opposite sides of the mould together. These bolts can be greased, and withdrawn when the concrete has hardened and before it has thoroughly set. Concrete is the easiest of all masonry work, and therefore the most suitable when skilled labour is scarce, in fact the only skill demanded is in the making and staying of the moulds.

Asphalt.—An excellent flooring, proof against damp and insects, is made by melting in an iron pot 100 parts of asphalt and one of tar; sand or stone-breaker screenings may be added if desired in the proportion of one to four. The surface to be asphalted must be thoroughly dry, and may be covered with stone chippings or screenings. It is divided into sections by thin straight-edges, set level and well greased. The tops of these straight-edges must stand at the level of the finished floor, and will therefore project from ½ to 1 in. above the surface to be covered. They should divide the floor area into sections that can conveniently be filled at one melting. The mixture must be smoking hot when poured, and worked level, as it cools, by a greased staff passed over the tops of the laid strips. After the strips have been withdrawn the grooves can be run up with melted asphalt. A floor 1 in. thick requires 12½ lbs. of asphalt per square foot.

Roofing.—Galvanised iron is practically the only material used for covering roofs. It is generally corrugated, as corrugations add to the stiffness of the sheet. The following table includes allowance for lap, but iron of the same gauge by different makers varies slightly in width and covering capacity:—

Birmingham wire gauge	16	18	20	22	24	26
Weight in lbs. per sq. yd., approximate	32	24	19	16	13	11
Square feet covered per ton	650	850	1,150	1,300	1,550	1,850

Curved roofs for spans up to 25 ft. can be made by riveting the sheets together and stiffening the arch with tie bars at 10 ft. intervals; but unless securely fastened to the building, such roofs have not sufficient weight to withstand highwind pressures.

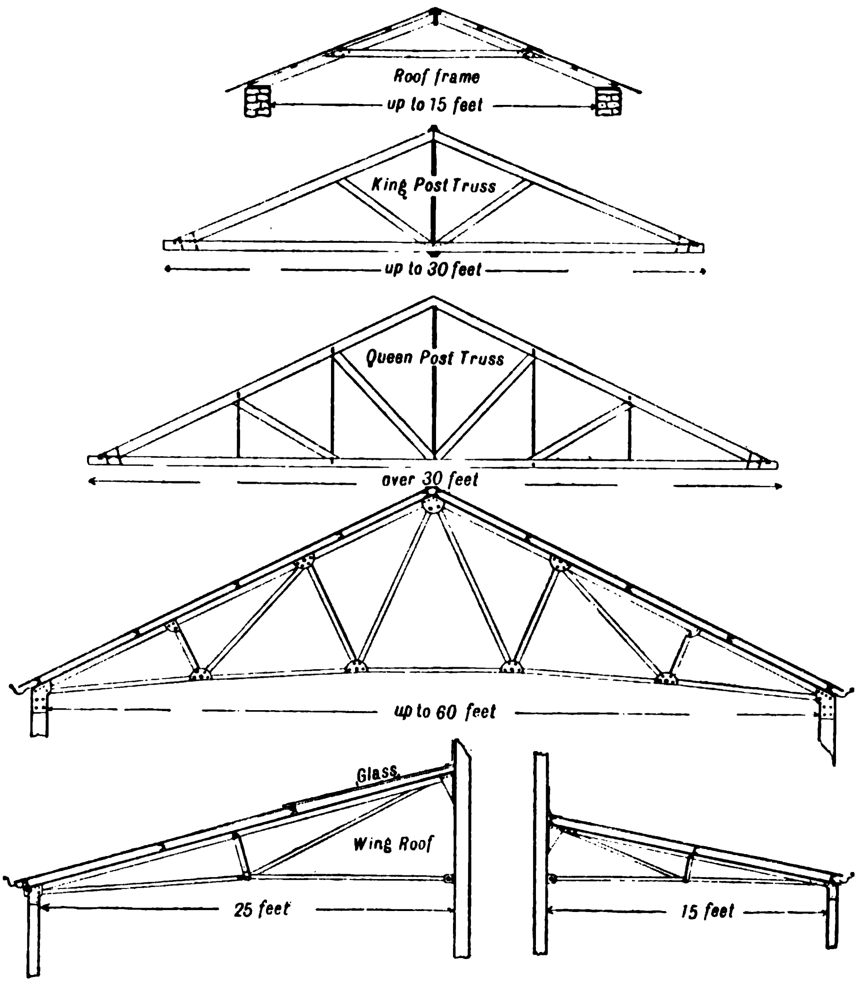


FIG. 87.—Roof Frames.

In tropical climates and countries subject to extreme variations of temperature the galvanised coating does not sufficiently protect the iron or steel plate within; the whole roof requires painting at intervals, but this precaution comes too late if corrosion has already started. A rise of one-fourth of the span is generally allowed, and more is seldom needed if a

6-in. lap is given in fastening the sheets; but in positions exposed to horizontal rain drift a rise of one-fifth is preferable.

In building roofs up to 15 ft. wide it is sufficient to incline the principal rafters, joint them to the ridge piece, and stiffen them by a tie-piece placed one-third of the rise above the wall plates. The purlins are spaced 3 or 3½ ft. apart, so that each sheet of roofing material is supported in the middle as well as the ends; the nails securing the iron to the purlins are, of course, passed through the convex part of the corrugations.

Roofs of more than 15 ft. in width are supported on frames, each frame being built separately; the two principals support the roofing sheets, and are connected at their lower ends by the tie-piece. This tie-piece protects the walls from the outward pressure of the principals, and is therefore in tension; as also is the king post, which supports the weight of, and prevents sag in, the tie-piece. This form of frame, known as the "king post truss," is used for spans up to 30 ft.; above this width two queen posts take the place of the king post, or the span may be divided into bays and wrought-iron bars used for the tensional members. This substitution saves much weight in wide spans; a roof 40 ft. wide, for instance, would require a tie-beam at least 14 in. by 9 in., which could safely be replaced by a 1⅜-in. iron tie-bar.

The following sizes are largely in excess of those required to merely support the iron sheeting, but will not be found too heavy for high wind pressures. The dimensions of the purlins depend on the spacing of the main frames, which varies from 6 to 10 ft., 8 ft. being an average.

Wood Roofs.

Span in Feet.	Tie-Beam.	Principals.	King Post.	Struts.	Purlins.
	Inches.	Inches.	Inches.	Inches.	Inches.
12	...	3 × 4½	...	...	2½ × 2½
16	...	3 × 5	...	...	2½ × 3
20	7 × 4	3 × 5½	4 × 5	3 × 4	3 × 3
25	9 × 4	4 × 5½	4 × 5	3 × 5	3 × 3½
30	10 × 5	4 × 6	4 × 6	3 × 6	3 × 4

Iron Roofs.

Span Feet.	Tie-Rod.	King Bolt.	Queen Bolts.	Struts, T-Iron.	Rafters, T-Iron.
Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
35	1⅛	⅞	(2) ¾	(4) 2¼ × ¼	3 × 5/16
40	1¼	1	(4) ¾, ⅝	(4) 2½ × 5/16	3¾ × 7/16
45	1⅜	1⅛	(4) ⅞, ¾	(4) 2¾ × 7/16	4 × ½
50	1½	1¼	(4) 1, ⅞	(6) 3 × ⅜	4 × ½
60	1¾	1⅜	(6) 1⅛, 1	(6) 3½ × 9/16	4¾ × 9/16

Iron is largely used in building engine, boiler, and battery houses, and will be found economical where timber is scarce and masons and carpenters highly paid; the erection is an easy matter, requiring careful supervision rather than skilled labour. Such buildings are subject to little deterioration if painted at intervals; they are neither inflammable, nor liable to be damaged by insects. The members are various sections of **H**, **T**, channel, and angle iron, the uprights resting on sole plates bedded on concrete, and the galvanised sheeting bolted to the horizontal bracing. The ordinary design of vertical and horizontal members is not sufficiently stable against wind pressures; a building only 150 ft. by 20 ft. might easily experience a pressure of 40 tons, with wind at only 30 lbs. per square foot; the required strength can be obtained by bracing the end bays of each side. In erecting, the post holes are filled with concrete to the level of the sole plates; the two end bays at each corner of the building are then put up with their bracing, and will be self-supporting. All intermediate vertical members can be lined off from the end bays; only their bases need be lined, any slight deviation at the top being rectified by the wall plates and roof frames; the latter are generally put together on the ground and hoisted into position with a guy pole.

Painting.—Comparatively few mines make use of paint to the extent necessary for the protection of exposed wood and iron work; it is regarded rather as an ornament than a protection. In many cases green unseasoned timber is used in construction work, and it is then undoubtedly right to delay painting for some time, as both paint and tar hasten the decay of unseasoned timber.

Paint consists usually of white, or carbonate of, lead, ground with linseed oil and mixed with various colouring substances; the proportions are—six pints of raw and one pint of boiled oil to twelve pounds of lead and colouring matter. A pint of turpentine or quarter of a pound of driers is added, the driers being litharge or acetate of lead. White oxide of zinc should not be used as a substitute for lead, it dries very slowly, has not the same covering power, and does not afford the same protection. Black paint is a mixture of lampblack and oil; a small quantity of white lead, about 5 per cent., may be added to give body to the mixture. White paint with 2 per cent. of lampblack becomes lead colour; red lead or ochre is added for red paint; verdigris for green, indigo for blue, an addition of indigo and lampblack giving a useful silver grey.

The following tints may be prepared by mixing colours in different proportions:—

Brown	Red and black.	Chestnut	White and brown.
Pearl	Lead colour and blue.	Chocolate	Black and red.
Orange	Red and yellow.	Straw yellow	White and yellow.
Olive	Blue, black, and red.	Buff	Yellow, white, and little red.

Before painting resinous woods the knots must first be stopped to prevent them from oozing; this is done with a mixture of red lead and size (thin glue), applied hot, and afterwards rubbed down. After the nail-holes have been stopped with putty, the whole surface can be cleaned down and a priming coat laid on; two or three more coats will be required, time being allowed for each to dry. When a highly finished surface is desired, each coat is rubbed down with fine glass paper, or pumice-stone and water, and one or more coats of varnish laid over the last coating of paint. In ordinary work 1 lb. of paint covers 4 superficial yards in the first coat and 6 yds. in the second; a gallon covers 50 sq. yds. of woodwork and 70 sq. yds. of ironwork.

In renovating old work the surface must be cleaned with hot water, soap, and sand; if greasy, a coating of whitewash should be given, and rubbed off when it has absorbed the grease; if blistered, the old paint must be entirely removed by scraping or scorching, and the surface afterwards cleaned down with sandpaper or pumice stone.

Whitewash.—A useful wash is made by adding slaked lime to the water in which rice has been boiled, or the sizing effect of the rice-water may be obtained by adding gum or weak glue to the wash. Various tints can be given to the wash by adding ochre, charred cocoa-nut shells, and other substances.

CHAPTER XVII.

TACKLE AND TOOLS.

Chains—Ropes—Pulley Blocks—Winches—Sheer Legs—Anchorages—Lifting Headgears and Pumping Bob—Capstans—Workshops—Wood-working Tools—Circular Saws—Fitting Shop Tools—Smithy—Fans and Blowers.

THE cost of erecting machinery and of carrying out construction work depends largely on the gear in use, on the blocks, falls, jacks, and winches being at hand and in good order. As a rule such tools receive rough treatment and little attention, being generally left where last used until required on the next occasion; even in use they are strained unnecessarily by being worked under disadvantageous conditions. Through continued ill-use and inattention they become less efficient, unreliable, and a possible source of danger to those using them. The first step in the right direction will be the provision of a tool house or room, in which all portable tools are kept, and to which they are returned when the job they were taken out for is completed.

Chains.—The chains in general use have links made from $\frac{1}{4}$-in. to $\frac{1}{2}$-in. iron, $\frac{3}{8}$-in. being an average size; they vary in quality, what is known as short link crane chain being of higher grade than the ordinary, thus the length of the link is an indication of the quality of the chain. The quantity required depends on the work in hand; at least two lengths of 200 ft. each are necessary for reeving blocks, two lengths of 100 ft. each for guys, and numerous other shorter pieces for slings. The smaller sizes of flexible wire rope make good guys, but are not as easily fastened as chain; one of the simplest fastenings for such ropes is to clamp the end to the standing part, after taking two or more dead turns around the object to be fastened.

Chains deteriorate not so much through use as want of attention, through being left lying on the ground until next required; a few minutes are well spent in coiling the length on some old planks and arranging a rough covering. Once a year the whole length should be drawn through a smithy fire, each link being heated to a dull red and annealed by being allowed to cool slowly; an opportunity for careful inspection is thus afforded and links that are strained, distorted, elongated, or show flaws, may be removed before damage is done.

The safe working load of a chain in tons is found by squaring the number of eighths of an inch in the side of the link and marking off the last figure on the right as a decimal. Thus $\frac{3}{8}$-in. chain, 3×3, equals 0.9 ton; 1-in. chain, 8×8, equals 6.4; the breaking strain of such a chain would be about 40 tons, but a wide margin of safety is necessary to provide for surges in the load and possible defects in the links.

Ropes.—The hemp and manilla ropes used as falls are $\frac{7}{8}$, 1, and $1\frac{1}{4}$ in. in diameter; smaller sizes being employed for lashing gear, light stays, and other purposes. All new ropes should be uncoiled from the inside and well stretched before use; one way of accomplishing this is by suspending them in the shaft with a weight at the lower ends.

Ropes should be protected from the weather as much as possible and also from white ants, which can do irreparable damage in a few hours; when no longer required they should be coiled "with the sun" and hung in the tool room.

The breaking strain of hemp ropes in tons is the circumference squared and divided by five.

Diameter, in inches	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2
Circumference, in inches	2	$2\frac{3}{4}$	$3\frac{1}{8}$	$3\frac{1}{2}$	4	$4\frac{3}{4}$	$5\frac{1}{2}$	$6\frac{1}{4}$
Weight, lb. per yard, hemp	$\frac{7}{8}$	1	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{3}{4}$	$3\frac{1}{2}$	$4\frac{1}{2}$
Working load, cwt., hemp	6	8	12	13	20	25	32	40
,, ,, ,, Manilla	5	6	9	12	15	20	26	32

Pulley Blocks.—It is essential in blocks that the sheaves be large in diameter to reduce the bending strain on the fall, and be of ample width for the size of fall to be used, otherwise the fall may run stiffly and be chafed by the sides of the block. A little care is necessary to avoid twisting the fall in reeving it, and it will be found a good plan to lay both blocks on the ground about 6 ft. apart, the hooks or bows being outwards. The fall is then reeved through the top sheave of the block which is to be uppermost, say from right to left, and is then passed through the upper sheave of the other block in a contrary direction, from left to right; then through the remaining sheaves of the two blocks, retaining the same directions.

In lifting heavy weights the sheaves of the upper block may not be in line with the winch, and the fall leading to the winch will be chafed by the sides of the block. This may be prevented by passing the fall from the winch not through the upper block, but through a separate snatch block, which is free to follow the resultant of two strains in different directions.

The strain on the fall is equal to the weight lifted divided by the number of turns of fall leading to or from the lower block; in lifting 5 tons with double and treble blocks, if the end of the fall is fastened around the third sheave of the upper block, there will be four turns leading to the lower, and

the strain on each $1\frac{1}{4}$ ton. But if the end of the fall is passed around the third sheave of the upper block and brought down and fastened to the weight, there will then be five turns of the fall, and the strain on each 1 ton. These are the theoretical strains; in actual work they are largely increased by friction up to as much as 50 per cent., and even more when the falls are twisted or badly reeved.

The many forms of differential chain blocks are self-sustaining and useful for vertical lifts, but when the power and weight act in different directions the chains often fail to mesh accurately with the sprocket wheels; the same trouble may also arise through twist in the chains, wear of the sprockets, and stretching of the links. Twist is easily removed by lifting the chain from the wheel and turning it, but the other two causes cannot be remedied and waste time enough to pay for new gear. Lifting and lowering are performed at the same speed—both are slow; and unless the blocks are made by a firm of repute, they cannot be depended on to carry the load stamped on them.

Winches.—The hand winches are generally double purchase, the larger ones lifting a ton direct from the barrel; wrought-iron frames are preferred as they are less liable to injury, at the same time they offer a much less rigid support than cast-iron framing. The frame itself is bolted to two runners, each about 5 in. by 4 in. by 12 ft. long, the outstanding ends being loaded with any convenient weights to secure an anchorage. Before loading the winch the barrel must be set square with the direction in which the fall is to lead, and the runners must be level and well bedded; should they be unevenly set or free to spring under strain, a large proportion of the power applied will be absorbed in friction of the bearings. When fully loaded down, each shaft of the winch should turn easily by hand. If the end of the fall is attached to the barrel, in long pulls the diameter of the barrel is enlarged by successive layers of rope or chain, necessitating increased power at the handles. This can be avoided by taking three or four turns of the fall around the barrel and keeping the end taut by a man or two behind the winch. When these coils have traversed the length of the barrel they must be returned to the former end by nipping the fall with a chain attached to the front of the frame. The knot employed for nipping chain falls consists of two dead turns around the fall on the side nearest the winch and a half hitch on the side farther from the winch.

In winch work the pressure on the handle multiplied by the distance through which it moves is equal to the weight multiplied by the height it is lifted; the average pressure applied by each man at the handles may be taken at 15 lbs.

To ascertain what weight can be lifted with a given power, multiply the pressure on the handles by the diameter of the circle described by the handle in inches, and by the number of revolutions of the handle to one of

the barrel, divide the result by the diameter of the barrel in inches, the quotient is the weight in pounds.

Thus if four men are at a winch which has handles 15 in. long, the barrel being $7\frac{1}{2}$ in. in diameter and making one revolution to twelve of the handles, 60 lbs. × 30 in. × 12 revolutions divided by $7\frac{1}{2}$ in. equals 2,880 lbs., the weight that can be lifted, less allowance for friction.

The ordinary triangle answers very well for lifting weights that can be brought to it, as in unloading transport waggons; the three poles are connected by a cross pin at the top, the same pin serving to suspend the shackle to which the upper block is fastened. It is easily erected by pulling the foot of one leg towards the other two; when hoisted, the spread of the legs gives it sufficient stability, and guys are not required.

A pair of sheer legs afford a larger radius of action, as by slacking out the guys they can be swung considerably out of the vertical; this is especially the case when blocks and falls are used for the guys, and when the pull of the main fall is at right angles to the guys. The upper ends of the two poles are lashed together with chain or rope passed first around one pole, then around the other, like the figure 8; the sharper the angle and closer together the feet of the poles, the more direct the strain will be and the greater the weight that may be lifted. Height is also a factor in determining the strength, short legs of a given size being stronger than long ones; thus a pair of legs 6 in. square and 24 ft. long may be safely loaded to 3 tons, but the same legs, if only 12 ft. high, would carry double the weight. By moving each leg alternately the sheers may be made to command the whole length of a building or foundation.

The falls are secured to anchorage posts, and in dealing with heavy weights and lifting lofty structures, such as headgears, the anchorage is exposed to considerable strain. The trench to receive the post should be at least 6 ft. long and be sunk at right angles to the strain, with regard to both horizontal and vertical angles; the depth depends on the ground, probably about 5 ft.

The post is placed in the pit with two battens at the heel of it and behind it, and after the lower part of the trench is filled and rammed solid, two more battens are placed near the surface, in front of the post, on the side nearest the strain; these also are rammed solid. Such an anchorage can only fail if the post or battens break, or if the whole length of the trench gives way.

As illustrating the use of lifting tackle, let it be required to raise the two side frames of a timber headgear standing 80 ft. high, and let the lift be made from a level plain. A rough measurement of the timber and its weight per cubic foot show the weight of each side to be 4 tons. Since the whole of this weight will not at any time be taken by the tackle, it will not be necessary to make any further allowance, but simply provide gear strong enough for 4 tons.

If the winch to be used is capable of lifting a ton from the barrel there must be four turns of falls leading to the weight; to allow for friction we use a double and treble block, which will allow five turns of fall to lead to the weight, or even six if a leading block be used. To permit a possible pull of 1 ton, the falls will be $\frac{3}{8}$-in. chain, or $1\frac{1}{4}$-in. diameter rope. The winch will be fixed in the centre of the sheer legs, and about 110 ft. distant from the cap piece, on the side nearest the foundations; a good anchorage post will be required close in front of the winch. It is evidently useless to pull direct from the winch to the cap; in order to get a lifting effect the pull must be from a point higher than the cap piece. A pair of poles are therefore put up about 30 ft. in front of the winch, their tops being lashed as in the case of sheer legs. The main chains (two of $\frac{7}{16}$ in. each) pass from the anchorage post to the top of these risers, and the double sheave block is fastened to them; the anchorage chains must not be secured in any way to the risers, they lie in the fork between the poles, and are free to lift out of it when the main frame is hoisted sufficiently high. The treble block is now lashed to the cap of the main frame and the fall reeved, the last turn passing from the cap to the winch, either by the side of or over the riser posts. The feet of the frame to be hoisted must be prevented from sliding forward either by anchorage posts in front of them, or by being braced to an anchorage behind them. The cap end of the frame is then lifted 10 or 12 ft. by jacks or gin pole, and the fore-and-aft stays attached to it. The strain may now be taken by the winch; as the cap end lifts, the anchorage chains will also lift out of the riser posts, and the pull be direct on the anchorage post and winch. When half-way up the winch is placed in single gear, and before the vertical position is attained the back stay is tightened up and payed out slowly as the hoisting proceeds.

When the frame is upright and guys taut, the double block is cast off from the anchorage chains and made fast to the cap of the second frame; in this way the first frame acts as a riser for the second. As soon as the weight of the second side is fairly taken, the guy on that side of the first half can be cast off, and will not be in the way of the second half.

Before lifting either frame, posts are lashed projecting 6 or 8 ft. above their tops; to these posts the blocks for lifting the stringers connecting the two frames are fastened.

Fig. 88 shows the tackle used in lifting a 35-ton pumping bob to its position 40 ft. above ground level; with the exception of the "half-pieces" used under the lashing chains, all the timber was pitch pine, 12 in. square, and rested on the walls of the engine-house. The bob was first hauled by two winches up an inclined road to the engine-house floor, 12 ft. above the ground. Two pairs of three-sheave blocks, with leading blocks, reeved with $\frac{5}{8}$-in. chain, were then fastened to the pumping nose; and one pair of four-sheave blocks, also with leaders, reeved with $\frac{9}{16}$-in. chain, to the

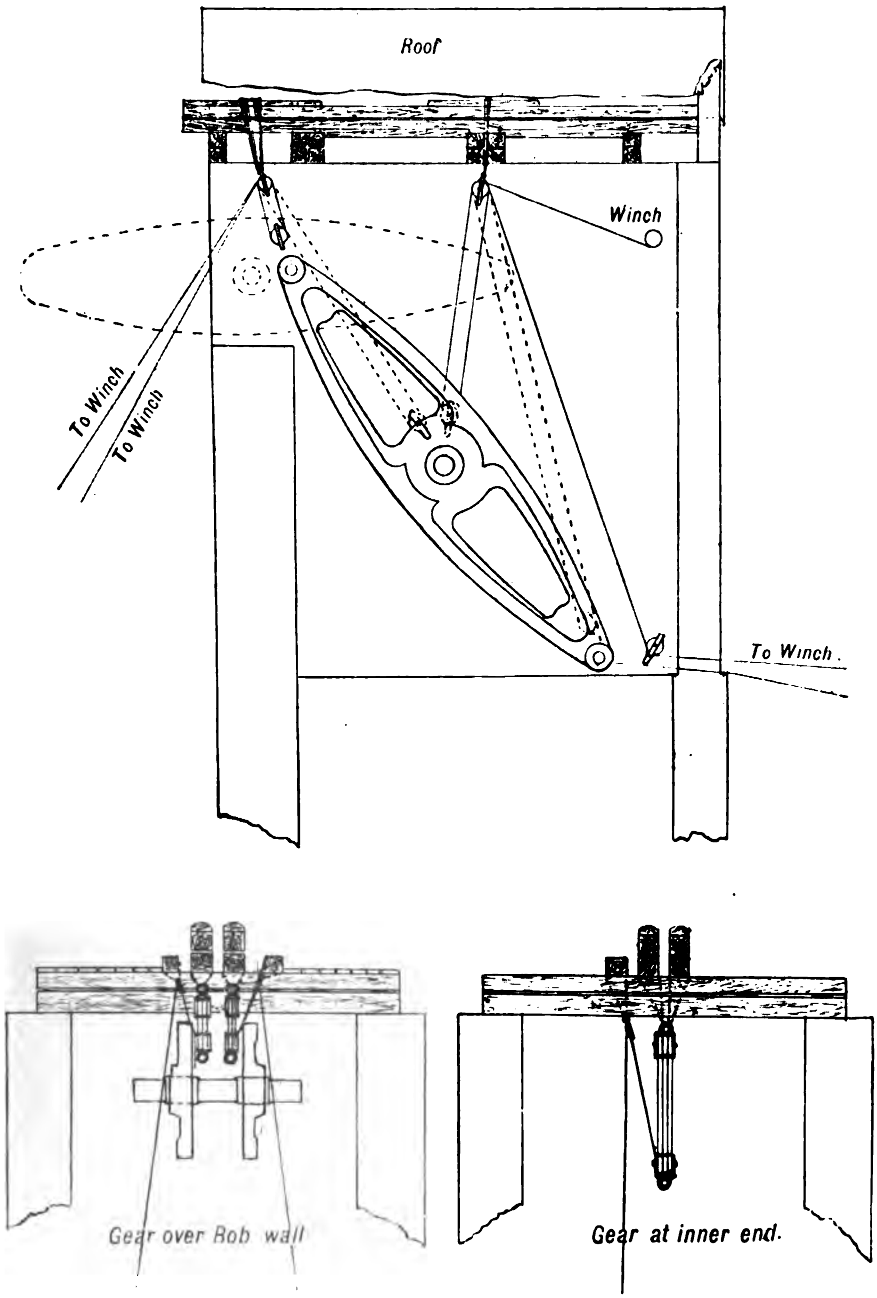


FIG. 88.—Arrangement of Tackle for lifting 35-ton Pumping Bob.

gudgeon. One winch at the foot of the inclined road was used to hold the bob back and keep its nose clear of the bob wall.

This arrangement lifted the bob to the position shown in the figure; the tackle was then shifted, as shown by the dotted lines, the three-sheave blocks being moved from the nose to the gudgeon, and the four-sheave block from the gudgeon to the inner end. When the bob had been well raised the fall in the four-sheave block was eased off, and the weight gradually transferred to the pair of blocks hanging over the bob wall.

Capstans.—The ordinary winch is often of insufficient power for handling pitwork, since only a limited number of men can work at the handles. If arranged with blocks and falls the motion is slower than is desirable. For heavy work a steam capstan is used, a double cylinder engine being arranged to drive the drum by worm gear; but the following plan answers very well where labour is abundant, it deals with pitwork up to 12 in. in diameter, and is useful for tightening ropeways and other purposes.

A sound baulk of timber about 11 ft. long is selected, and one end of it made round for a length of 3½ ft., the size of the rounded part being such that it will fit easily inside one of the pipes used for the pump column. This is now fixed as an anchorage post in a trench 8 ft. long by 7 ft. deep; it is supported on the front and back sides by battens 4 in. thick, and the whole trench firmly rammed in layers 6 in. thick. An ordinary pump "matching," 4 ft. long, is slipped over the round part of the post which projects above the ground. To the top flange of this matching are bolted the cross arms and the iron plates that help to fasten them. The lower part of the matching, where the capstan rope coils, may be lagged up to 2 ft. in diameter, with a round table 3½ ft. in diameter below the lagging to prevent the coils of rope from slipping off. The capstan bars will be about 10 ft. long, and the walk raised 1 ft. above the ground, leaving an opening for the rope to pass through.

Workshops.—The extent of the workshops required, and their equipment, depend partly on the size of the mine, but chiefly on its position. In remote districts the installation must be capable of carrying out all necessary repairs, and even when assistance is within reach time is often saved by doing the work on the spot. Some mines are so situated that fuel, constructional material, and general supplies are delivered on the property to order, while on others, not so fortunately located, the first step towards building a house is the selection of the growing timber in the forest. Naturally a more complete equipment of machine tools is required in the latter case, when the staff has to provide all that merchants usually supply.

Every mine will require a fitting shop, smithy, and carpenters' shop,

each of an average size of 50 by 25 ft.; the saw mill and moulding shed are separate structures, and not always needed.

Machine tools of the same kind vary greatly in price, but as the cost of the raw material is about the same in each case, the extra price pays for superior accuracy and finish; such a tool lasts longer, does more work, and does it better. It is in the end economical to buy good tools, and get them from makers who make a speciality of their manufacture. Should there not be sufficient work to employ a man at each machine, there should at all events be some one in charge of the shop, and responsible for the tools in it, to see they are kept clean, in good order, and not used by incompetent persons.

A lathe and a saw bench are generally the first tools installed, others are added at intervals, until the shops are capable of doing more than ordinary repairs, and undertake the manufacture of light spare parts. With the aid of a cupola and steam hammer the accumulation of worn iron and steel can be turned to account, and many mines turn out their own shoes, dies, tram wheels, rock drills, and many other things which provide useful work for spare time.

The workshops are usually grouped together and occupy a central position, the smithy being necessarily near the main shaft. Both fitting shop and smithy should be connected to the shaft by a tram line for conveying drill bits to be sharpened, trucks, rock drills, and pumps for repair.

A small equipment would comprise a saw bench, lathe, two drilling machines, screwing machines for pipes and bolts, a grindstone, and pair of emery wheels—these tools, in fact, being almost indispensable on every mine.

Wood-working Tools.—Such sawing as is required is usually done by circular saws; they take a wider cut than band saws, and therefore waste more lumber. But this is not an important point, and the circular form is the simplest; it can be run by men who would be unable to handle either a band or a gang saw.

The saw used should not be larger in diameter than is necessary for the cut; the fronts of the teeth are tangential to a circle from one-third to one-half the diameter of the saw; the backs of the teeth should be well supported and have no more clearance than a clean cut requires. For hard woods, the clearance is about right when a line drawn along the back of the tooth touches the point of the next tooth but one. See Fig. 89. Under similar conditions a fine-toothed saw takes more power to drive it and makes a smoother cut, while a coarse pitch of tooth requires the support of a stiffer blade and takes a wider cut. In saws set with the ordinary tool, the setting is generally irregular, some teeth project more than others, and the result is rough lumber, requiring considerable dressing to work it down to a fair

surface. An even set is ensured by an angle block, such as is used for bolting work to lathe face plates, two or more edges being bevelled off to different angles. See Fig. 89. This tool is held against the saw, and each tooth struck with a light hammer about one-third up from the point to the root; in this way, each tooth is set to the bevel planed on the block; in Fig. 89 the middle tooth is in position for setting.

Saw benches are useful for cutting lumber to dimensions, and even for squaring up logs on which one side has been adzed flat, but cannot be successfully employed in breaking down round logs; when used on hard woods, the feed is altogether too fast and the saws themselves seldom stiff enough.

For dealing with round logs a travelling carriage is required; the log is secured to the headstocks by dogs, and fed forward at the end of each cut by a lever at the end of the carriage. This lever feeds forward all the

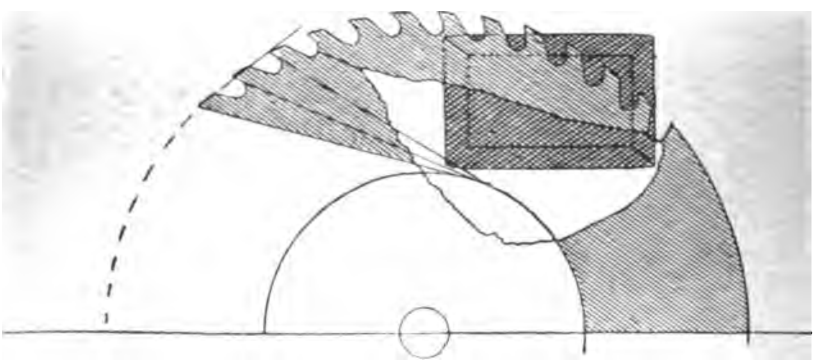


FIG. 89.—Saw-setting Block.

headstocks simultaneously, and works up to an adjustable stop, set for the thickness of lumber required.

Thus if the stop is set to give a feed of 1 in., planks of that thickness will be cut, provided the lever is moved up to the stop. The mill is preferably arranged to receive logs at one end, and deliver the finished lumber at the other; the foundations must be substantial, as the speeds are high, and all vibration fatal to good work.

The saws and feed shafts are carried on a frame, either of wood or cast iron, securely bolted to the foundations; the rails on which the carriage runs are planed to an inverted V, they must be laid perfectly parallel with the saw blade and fastened to timber bearers, these bearers being either mounted on sleepers or supported on walls of masonry or concrete. If water is not available for sluicing out the sawdust, a tram line should run into the pit, as the accumulation is considerable when much work is done. An arrangement of step pulleys provides for varying the rate of feed,

according to the depth of the cut, but even the slowest speed is generally 50 per cent. too fast for dealing with really hard wood.

Saws of more than 5½ ft. in diameter have not the necessary stiffness; for deeper cuts two saws are employed, the smaller of the two being set above and slightly in advance of the main saw; a combination of this description is capable of dividing a 4-ft. log in the middle. For all heavy work the American pattern saw, with removable teeth, can be recommended; as the points of the teeth are widened by swaging to give the required clearance, the width of cut taken is slightly more than with the ordinary saw; but if lumber is so scarce that the width of a cut is valuable, it is better to discard the circular type and use band saws. On the other hand, the diameter of the saw is not being constantly reduced by sharpening, and a fresh set of teeth can be put in in far less time than would be required to file up an ordinary saw. The blunt teeth can be swaged and sharpened at leisure, but they are cheap enough to discard after one or two filings. When using any form of circular saw on hard wood, it is advisable to let a jet of water, about ⅛ in. in diameter, play on the teeth as they emerge from the cut; this keeps the points cool and the spaces clear.

When the mine is called on to supply all the dimensioned lumber required, a planing and thicknessing machine is a valuable acquisition, especially if additional cutter heads are fitted adapting it to moulding and grooving work. With a good grindstone and an emery wheel machine the wood-working department will be fairly complete; but unless inserted tooth saws are used, a saw-sharpening machine should certainly be added to the list.

The **Fitting Shop** will require at least two lathes; both should be screw cutting and have gap beds. The smaller one, about 6-in. centres and 6-ft. bed, and fitted with a self-centring chuck, is specially useful in rock drill repairs, turning the shanks of drill bits and other small work.

The larger lathe, about 9 or 10 in. high, should be provided with a bed long enough to take a stamp stem between centres, and a clear space should be left behind the movable head so that long lengths of shafting may be dealt with. The sliding carriage should be of ample area so as to hold cylinders that are to be rebored, a form of repair which largely increases the life and efficiency of small engines, pumps, and rock drills. All machine tools should be placed so that the light is thrown on the work, and not intercepted by the body of the operator; the feet should rest on substantial concrete piers. Even a massive bed is easily deflected by indifferent supports, and it is essential that the surface be level and free from winding; it may be tested with a spirit-level, and by looking over straight-edges placed across the bed at various points.

The alignment of the mandrel may be tested by applying a straight-

edge to a true face plate and checking it by a square placed against the edge of the bed. The accuracy of the back centre can be tested by squaring and polishing the end of a piece of 2-in. bar iron, about 3 ft. long. This is held in the chuck, and while revolving, a fine circle is scribed on the outstanding end; the back centre, when brought up, should mark the centre of this circle.

The **Shaping Machine** should have a stroke of not less than 12 in., be fitted with a vice for holding small work and a mandrel for dealing with hollow goods. Even when a power shaper is not installed, every mine should have one or two hand machines; these useful little tools have strokes of 6 and 8 in., take a cut ⅛ in. deep, and soon save their cost in files and labour. The price varies from £6 to £12, and an attachment can be fitted for cutting keyways in wheels.

A **Planing Machine** will only be found in well-established mines; the table having a stroke of 4 to 6 ft., takes work beyond the range of the shaper. It is useful in trueing up slide valves and valve chests of engines, drills, and pumps, cutting keyways in shafting, and many other purposes.

Drilling Machines.—One or two ordinary machines, capable of boring 1½-in. holes, will be required, and also a higher class tool for work demanding greater accuracy. A 4-ft. radial drill answers the purpose, and may be fitted with a boring bar working through a bushing in the table.

Screwing Machines.—A useful machine for all-round work can be obtained, which will screw pipes from 1 to 4 in. in diameter, and bolts from ½ in. to 2 in. It is arranged to work either by hand or power; the price is about £65, which includes cutting off gear.

A **Grindstone** and a pair of emery wheels complete the tool list; the wheels should be arranged for wet grinding, as the dust is detrimental to the other machines. Probably a section of the shop will be devoted to rock drill repair, and it will be found a great convenience to fit a tank containing boiling soda solution, in which the parts of the drills are rapidly cleaned. This arrangement saves time and avoids much dirty work. Air for testing the machines will be laid on, and a stand fixed on which they can be tested.

Another section of the shop may be arranged as a lock-up store for such supplies as are constantly required, such as rock drill spares, pump valves, packing, and jointing. It may also serve as a tool room for portable gear.

The Smithy.—In laying out the smithy the hearths and anvils must be conveniently placed with relation to each other, the fires hooded over to carry off the smoke, and water laid on for cooling the tuyeres and for tempering. It is by no means an economical plan to draw blast from the air pressure mains. The fires require volume of air rather than pressure. If compressed air is to be used, it is best to direct a small jet into an open cone behind the hearth and cause an induced draught. On the whole, a fan or blower is preferable; the former works at a high speed and is conveniently driven from the wood-working machinery shafting, the air being led to the smithy either in pipes of ample dimensions or in a brick culvert.

FANS.

Diameter.	Revolutions per Minute.	H.P. Required.	Belt Width.	Pulley Diameter.	Smithy Fires.
Inches.			Inches.	Inches.	
13	1,800	½	1½	5	4
16	1,700	¾	2	5	6
19	1,600	1¼	2½	6	9
22	1,500	2	3	7	12
25	1,400	2½	3½	8	16
30	1,300	3	4	9	25

The blower works at a slower rate, but is more positive in its action and gives a higher blast pressure. The two vanes are generally made of wood, and are liable to swell and stick in damp situations and rainy seasons. They are not intended to work in actual contact with each other, and when turned slowly by hand should not be tighter at one part of the revolution than another. Should the vanes have more clearance than is desirable they can be recoated, and melted composition being applied to the hollows, not the rounded edges, of the vanes. Before coating, the hollows should be scraped clean, and if the vanes are removed from the casing, they must be replaced in the same relative positions, with the same teeth of the spur wheels in gear.

ROOTS' BLOWERS.

Number.	Revolutions per Minute.	H.P. Required.	Cubic Feet of Air per Minute.	Diameter of Air Main.	Smithy Fires.
2A	350	¾	600	5 in.	4
1A	350	1	800	6 ,,	6
1	400	2	1,300	7 ,,	10
2	400	4	2,000	8 ,,	18
3	380	6	3,000	10 ,,	30
4	380	8	4,500	12 ,,	50

Drilling and bolt screwing machines may be placed in the smithy, and in the early stages of work a rock drill can be turned into a useful little hammer. Should a larger hammer be installed at a later date, it should be driven by compressed air, as its intermittent use leads to considerable condensation if steam is employed.

Drill sharpening machines have long passed out of the experimental stage, and are worth installing if only six machine drills are used. The various makes are alike in principle, the bits being compressed between dies, just as drop forgings are, and correct size and shape assured. Machine sharpened bits are uniform in gauge, clearance, and cutting angle, and will be found to do more work than those sharpened by hand. Cross bits can be sharpened as easily as any other form and may be used throughout the mine, an arrangement which reduces the number of bits required per shift and also the waste of steel.

The Ajax is one of the simplest of these machines, and consists substantially of two modified rock drills, one set horizontally and the other vertically, each being provided with suitable heads, anvils, and dies. The quantity of air consumed by the machine when fully employed is about equal to one ordinary rock drill. From 1,200 to 1,500 bits are sharpened in twenty-four hours, though two men with only two weeks' experience have turned out as many as 300 in four hours.

CHAPTER XVIII.

DETAILS FOR ESTIMATES.

Boilers—Water Power—Pumping—Hoisting—Air-Compressing—Rock Drills—Ore Treating—Gold Extracting—Diamond Drilling—Transport.

SOME outline specifications which had been prepared for insertion in this chapter have on second thoughts been omitted, as the engineer whose training enables him to fill up the blanks will hardly need such outlines as a guide. Instead of attempting to define the details and proportions of the machinery, it will, in most cases, be better to state clearly what work is to be done, under what conditions the duty is to be performed, and, broadly, the means considered most advisable.

Even in these respects the information from the mine is often less complete than it might be, and some details for estimates are here offered as an aid in avoiding these omissions. The various points on which information is required are enumerated, and a glance through the lists may bring to mind something momentarily forgotten, saving delay in the execution of the order or expense in cabling further particulars.

The information given should be sufficient to enable the directors to call for tenders and place the order without being troubled by the conflicting claims of rival manufacturers; a provision all the more necessary as the board seldom has the assistance of disinterested advice on mechanical matters.

Boilers.

1. Type required—vertical, Cornish, Lancashire, tubular, or water-tube.
2. Evaporative power required ; or,
3. Description of engines and their indicated horse-power.
4. Test pressure. Working pressure.
5. Size of each unit ; or,
6. Weight conveniently handled in transport.
7. Demand for steam, regular or irregular.
8. Fuel to be used, description, quality, heating value.
9. Feed water, its purity and temperature.
10. Average daily temperature.
11. Attendants, skilled or otherwise.
12. Smoke stack required, complete with base plate and guys.
13. Flues or breechings for connecting boilers to stack.
14. Mountings, fittings, valves, gauges.
15. Pipe connections for steam, feed, blow-off.
16. Firing and cleaning tools, hose for cleaning tubes.
17. Jointing materials.
18. Non-conducting composition.
19. Spare firebars, bearers, gauge glasses. Boiler tubes.
20. Special seating bricks, firebricks, ordinary bricks, lime.
21. Tackle, boiler carriage, jacks, gear.
22. Feed pumps, feed heater, superheater.
23. Tanks, feed filter.
24. Materials for boiler-house.

Water Power.

1. Height of fall, from surface of intake to surface of tail race.
2. Quantity of water available.
3. Brake horse-power required, constantly or intermittently.
4. Is storage of water possible? to what extent in proportion to the quantity used?
5. Is economy in the use of water essential?
6. The axis on which the wheel revolves to be vertical or horizontal.
7. Governor required to regulate the speed.
8. Speed variation permissible.
9. Direction in which the wheel is to revolve.
10. Speed at which the driven shafting is to revolve.
11. Is the space limited in any direction?
12. Piping, bends, valves, gates, screens, air and safety valves.
13. Contour of ground on which the pipe line is to be laid.
14. Shafting, belts, ropes, bearings.
15. Timber for wheel frame, flume, housing.
16. Building materials, cement, lime bricks.

Pumping Engines.

1. Type—geared, direct, single or double cylinder, compound, condensing.
2. Approximate quantity of water to be raised per minute.
3. Any increase to be allowed for in wet seasons.
4. Height of lift. Allowance for possible increase.
5. Steam pressure available.
6. Weight of heaviest piece not to exceed .
7. Distance from engine site to shaft.
8. Shaft vertical. Angle of inclination with horizon.
9. Bob. Balance box. Connections to engine and pump rods.
10. Steam and water connections.
11. Jointing materials. Tackle for erecting.
12. Building materials, lime, cement.
13. Materials for engine-house.

Direct-Acting Pumps.

1. Type—simple, compound, duplex.
2. Double-acting, bucket type ; plunger, or double plunger.
3. Quantity of water to be raised per minute.
4. Water, clean, gritty, acid, salt.
5. Height of lift.
6. Steam or air pressure.
7. Distance from pump to boiler.
8. Position of pump, vertical, or horizontal.
9. If for sinking purposes, to work suspended.
10. To condense its exhaust steam. Water cylinder to be fitted with renewable liner.
11. Water valves rubber faced. Packing. Cup rings.
12. Hose connections for steam, for suction.
13. Piping for steam, exhaust, suction, delivery.
14. Foot valve. Strainer. Cut-off valve to column.
15. Spare valves, springs, packing, leather, hoses.
16. Gear for slinging and lowering.

Pitwork.

1. Quantity of water to be raised per minute; water acid or salt.
2. Height of lift; possible increase.
3. Length of pumping stroke.
4. Power available.
5. Shaft vertical or incline; angle with horizon.
6. Dimensions and sketch of pumping compartment, showing position of main rod, if fixed.
7. Lowest fixed lift to have a working barrel at the foot of the column.
8. Suction pipes to be straight, or diverted to catchments.
9. Main rods required, complete.
10. Catch wings and fittings.
11. Timber for bearers, guides, rollers, cisterns.
12. Guide rollers for incline shaft.
13. Priming pipes to valve boxes.
14. Sinking lift required complete.
15. Rods for sinking lift, pin plate, set off.
16. Spare sinking windbores, clacks, seats, bucket forms, prongs.
17. Joint rings and bolts. Leather for gearing buckets. Packing.
18. Capstan rope.

Hoisting Plant.

1. Type of engine—duplex, compound.
2. Drums, single or double; fixed on the shaft, or free.
3. Gross weight of load.
4. Winding speed in feet per minute.
5. Steam pressure available.
6. Depth of mine; possible increase.
7. Dimensions and sketch of winding compartment.
8. Distance from shaft to engine.
9. Brakes to be post, or band; actuated by hand, foot, or steam.
10. Reversing gear, hand or steam actuated.
11. Indicator fixed, or adjustable.
12. Handles all controlled from one position.
13. Heaviest piece not to exceed .
14. Headgear, steel, or timber; height of ore delivery above ground; angle of shaft, if inclined.
15. Winding ropes, sheaves, detaching hooks.
16. Skips, self-dumping; spare ones and parts.
17. Cages, safety catches, trucks, rails.
18. Building materials for foundation and house.

Air Compressors.

1. Type—single duplex, compound, Corliss gear, condensing, two-stage.
2. Motive power to be steam, water, or electricity.
3. To be driven direct, or by ropes or belts.
4. Cubic feet of air to be compressed per minute.
5. Or the number and bore of drills, engines, or pumps to be worked.
6. Steam pressure available. Air pressure required.
7. Automatic regulation to be provided.
8. Altitude above sea level.
9. Description of air valves to be supplied.
10. Receiver, fittings, connections. Recording pressure gauge.
11. Intercooler, reheater, and connections.
12. Particulars of air mains, length required, number of bends, connecting branches, valves, reducers, drain cocks.
13. Length required of distributing pipe, valves, and cocks.
14. Water service pipe to cylinder jackets, to drills, to condenser.
15. Steam connections to boiler.
16. Limit of weight for transport.
17. Spare spring rings, bearing brasses, valve springs, buffers.
18. Building materials for foundations, for house.
19. Foundation plan.

Rock Drills.

1. Number of machines required; maker; size; spare ones.
2. Nature of rock to be bored, hard, or seamy.
3. Drill bits to have parallel or taper shanks.
4. Diameter and depth of average holes.
5. Number of columns required, their length; single or double screw.
6. Number of clamps and arms.
7. Drill bits, their number, length, and pattern.
8. Sharpening tools; sharpening machine.
9. Hoses, connections, unions, air cocks, sand pumps.
10. Electric blasting, wires, detonators, battery.
11. Spare parts—U bolts; piston rods, rings, and springs; buffers; ratchets and ratchet wheels; twist bars and nuts; feed screws and nuts; front and back covers; cradles; packing glands; valves; tappets or rockers; bolts; hoses and fittings; marline; steel for bits.

Ore Treating.

1. Stamps; number of heads and weight of each.
2. Framing of iron or wood. Foundation piles to be supplied.
3. Ore bins. Grizzlies. Automatic feeders.
4. Belt conveyors. Elevators.
5. Amalgamating tables, plain surface or silvered.
6. Stone breaker, belts and shafting for same.
7. Screens, description and mesh.
8. Line shafting, battery belts.
9. Spare heads, shoes, dies, cams, cam shafts, stone-breaker jaws, and springs.
10. Clean-up pans, shafting and belts.
11. Water service pipes, cocks, pumps. Tank.
12. Buckets; pans; scales; quicksilver; wash leathers.
13. Retort. Ingot mould. Amalgam safe. Strong room.
14. Motive power, allowance for possible extension. Spare wearing parts.
15. Amalgamating pans. Settlers. Shafting and belts for same.
16. Spare dies, mullers.
17. Concentrating machines, shafting, belts. Speed of shaft from which the concentrators are to be driven.
18. Tube mills, shafting and belts for driving; spare liners, flints.
19. Filter presses, cloths; hydraulic pumps.
20. Cyanide vats, daily capacity required.
21. Duration of treatment. Leaching qualities of ore.
22. Vats to be of wood, shape.
23. Tanks for solutions, for washes, and for sump.
24. Precipitating boxes.
25. Cyanide, zinc, crucibles, fluxes.
26. Pumps and piping.
27. Motive power. Zinc lathe.
28. Trucks, rails. Incline hoist. Discharge crane.
29. Materials for houses and construction.

Diamond Drilling.

1. Boring to be done from surface, or underground.
2. If underground, the space available.
3. If from surface, the depth of deposit overlying solid rock.
4. Kind of rock to be bored, hard, seamy.
5. Maximum depth required to be bored.
6. Approximate total drilling to be done.
7. Diameter of core required.
8. Motive power, steam, air, electricity.
9. Boiler required, complete, portable.
10. Pump, water piping.
11. Portable steel headgear, height.
12. Drill runners required, able to set crowns.

Extras Required.

A complete outfit is supplied with each machine, but extra wearing parts are necessary if the drilling is to be done out of the United States. Only 200 ft. of drill rods are included with the machine; the additional rods for greater depths must be ordered as extras.

Casing pipe. Drive pipe.
Chopping bits. Reamers.
Drill rods. Blank bits.
Core barrels. Core lifters. Length of extra core barrels.
Carbons. Hoisting rope.
Pipe dies, taps, tongs, cutters.

Railway.

1. Plan and contour of proposed line.
2. Total length of line and branches.
3. Nature of traffic. Daily amount in tons.
4. Approximate weight of heaviest load.
5. Number of curves, radius of sharpest curves.
6. Inclination and length of steepest gradients.
7. Sleepers of wood or steel, pressed or rolled.
8. Nature of ground and ballast to be used.
9. Points and crossings, right hand or left. Sidings.
10. Bridges. Wrought-iron culvert pipes.
11. Platelayers' tools.
12. Locomotives to haul tons ; at speed ; up gradients .
13. Fuel to be .
14. Water tanks. Water service pumps.
15. Traversing jacks. Spare parts for engine. Spare couplings.
16. Number of body trucks, platform trucks, timber and lock-up trucks
17. Bodies to be removable to form platform trucks.
18. Brakes to be fitted to each truck.
19. Gauge of all rolling stock.
20. Buffers and drawhooks.
21. Spare wheels, axles, springs, bearings, couplings.
22. Building material for stations, for sheds.

APPENDIX OF MISCELLANEA.

Angle and Tee Iron.

SECTIONAL AREA IN INCHES AND WEIGHT IN POUNDS PER FOOT.

Width of both Flanges Added.	Thickness.											
	$\frac{1}{4}$ in.		$\frac{5}{16}$ in.		$\frac{3}{8}$ in.		$\frac{7}{16}$ in.		$\frac{1}{2}$ in.		$\frac{9}{16}$ in.	
Inches.	Lbs.	Ins.	Lbs.	Ins.	Lbs.	Ins.	Lbs.	Ins.	Lbs.	Ins.	Lbs.	Ins.
3	2.31	0.69	2.82	0.84	3.31	0.99	3.77	1.12	4.2	1.26	...	...
3¼	2.52	0.75	3.08	0.92	3.62	1.08	4.14	1.2	4.62	1.38	...	...
3½	2.73	0.81	3.35	1.0	3.94	1.18	4.51	1.35	5.04	1.51	...	...
3¾	2.94	0.88	3.61	1.08	4.25	1.27	4.88	1.46	5.46	1.63	...	...
4	3.15	0.94	3.88	1.16	4.57	1.37	5.24	1.57	5.88	1.76	6.5	1.94
4½	3.57	1.06	4.4	1.32	5.2	1.5	5.98	1.76	6.72	2.01	7.44	2.23
5	3.99	1.19	4.92	1.46	5.83	1.74	6.71	2.0	7.56	2.36	8.39	2.52
5½	4.41	1.32	5.45	1.63	6.46	1.93	7.45	2.23	8.4	2.51	9.33	2.79
6	4.83	1.44	5.97	1.78	7.09	2.12	8.18	2.24	9.24	2.77	10.28	3.08
6½	5.25	1.57	6.5	1.94	7.72	2.31	8.92	2.67	10.8	3.02	11.22	3.3
7	5.67	1.69	7.02	2.1	8.35	2.5	9.65	2.88	10.92	3.28	12.17	3.65
7½	6.09	1.82	7.55	2.26	8.98	2.69	10.39	3.11	11.76	3.52	13.11	3.92
8	6.51	1.95	8.07	2.41	9.61	2.8	11.12	3.32	12.6	3.77	14.06	4.22
8½	6.93	2.07	8.6	2.57	10.24	3.07	11.86	3.55	13.44	4.02	15.0	4.49
9	7.35	2.2	9.12	2.73	10.97	3.25	12.59	3.98	14.28	4.28	15.95	4.78
9½	7.77	2.33	9.65	2.89	11.5	3.44	13.32	4.2	15.12	4.53	16.89	5.06
10	8.19	2.45	10.17	3.04	12.13	3.63	14.06	4.43	15.96	4.77	17.84	5.34

Alloys.

Fusible at boiling point.—8 parts bismuth, 5 of tin, 3 of lead. Increase the proportion of bismuth for higher temperatures.

Brass for bearings.—4 parts of copper, 1 of tin.

Brass, ordinary.—2 parts of copper, 1 of zinc.

Antifriction metal.—80 copper, 16 tin, 2 antimony, 1 lead.

Babbitt metal.—50 tin, 5 antimony, 1 copper.

Belting.—The horse-power transmitted by single leather belts equals the breadth in inches multiplied by the speed in feet per minute multiplied by 70 divided by 33,000.

For double leather belts multiply the above result by $1\frac{1}{2}$.

Birmingham Wire Gauge.

B.W.G.	In.	B.W.G.	In.	B.W.G.	In.
00000	$.500 = \frac{1}{2}$	10	.137	24	.25
0000	.450	11	$.125 = \frac{1}{8}$	25	.21
000	.437	12	.109	26	.20
00	$.375 = \frac{3}{8}$	13	.94	27	.18
0	.349	14	.80	28	.15
1	$.312 = \frac{5}{16}$	15	.72	29	.13
2	.284	16	$.63 = \frac{1}{16}$	30	.12
3	.261	17	.55	31	.10
4	$.250 = \frac{1}{4}$	18	.48	32	.9
5	.239	19	.42	33	.8
6	.208	20	.35	34	.7
7	$.187 = \frac{3}{16}$	21	.33	35	.5
8	.166	22	.29	36	.4
9	.158	23	.28		

Cement for Leather Belts.

Take 10 parts of sulphate of carbon, 1 part of oil of turpentine, add sufficient guttapercha to make a sticky mixture. See that the joint is free from grease, leave under pressure until dry.

Cement for Rubber Belts.

By weight 16 parts of guttapercha, 4 of caoutchouc, 2 of pitch, 2 of linseed oil, 1 of shellac; melt together and apply warm.

Cement for Steam Work.

1. Equal parts of red and white lead ground with linseed oil.
2. 10 parts of white lead ground in oil, 3 of black oxide of manganese, 1 of litharge.
3. 1 part of quicklime (lime that has slaked in a damp place), 1 part of fine sand, 2 parts of ground litharge, enough boiled oil to make a stiff putty. Dries quickly, does not keep.

Cement, Acid Proof.

Powdered glass mixed with a concentrated solution of silicate of soda.

Cement for Handles.

1. Rosin, 4 parts; beeswax, 1 part; brick dust, 1 part.
2. Rosin, 2 parts; sulphur, 1 part; add iron filings or brick dust.

Cement, Waterproof, for Tanks.

1. Melted glue, 8 parts; linseed oil, 4 parts; litharge, 2 parts; boil together.
2. Ground lime, 5 parts; fine sand, 5 parts; mix with boiled oil.
3. Glue, 4 parts; oxide of iron, 1 part; boiled oil, 1 part.

Cements, General Purposes.

1. 5 parts of fish glue, 5 parts of water, add 1 part of nitric acid slowly.
2. Grated cheese, thoroughly washed in hot water to remove the fat, mixed with an equal weight of ground lime.
3. 1 part of powdered resin, 10 parts of strong ammonia; allow to stand for several days before use.

Cement, Rust.

200 lbs. of iron borings or turnings moistened with water containing 2 lbs. of sal-ammoniac and 1 lb. of sulphur.

Circumferences and Areas of Circles.

Diam.	Circum-ference.	Area.	Diam.	Circum-ference.	Area.	Diam.	Circum-ference.	Area.
¼	0.7854	.04908	12½	39.27	122.71	53	166.5	2206.1
½	1.570	.1963	12¾	40.05	127.67	54	169.6	2290.2
¾	2.356	.4417	13	40.84	132.73	55	172.7	2375.8
1	3.141	.7854	13¼	41.62	137.88	56	175.9	2463.0
1¼	3.927	1.227	13½	42.41	143.13	57	179.0	2551.7
1½	4.712	1.767	13¾	43.19	148.48	58	182.2	2642.0
1¾	5.497	2.405	14	43.98	153.93	59	185.3	2733.9
2	6.283	3.141	14¼	44.76	159.48	60	188.4	2827.4
2¼	7.068	3.976	14½	45.55	165.13	61	191.6	2922.4
2½	7.854	4.908	14¾	46.33	170.87	62	194.7	3019.0
2¾	8.639	5.939	15	47.12	176.78	63	197.9	3117.2
3	9.424	7.068	16	50.26	201.06	64	201.0	3216.9
3¼	10.21	8.295	17	53.40	226.98	65	204.2	3318.3
3½	10.99	9.621	18	56.54	254.46	66	207.3	3421.2
3¾	11.78	11.044	19	59.69	283.52	67	210.4	3525.6
4	12.56	12.566	20	62.83	314.16	68	213.6	3631.6
4¼	13.35	14.186	21	65.97	346.36	69	216.7	3739.2
4½	14.13	15.904	22	69.11	380.13	70	219.9	3848.4
4¾	14.92	17.720	23	72.25	415.47	71	223.0	3959.2
5	15.70	19.635	24	75.39	452.39	72	226.1	4071.5
5¼	16.49	21.647	25	78.54	490.87	73	229.3	4185.3
5½	17.27	23.758	26	81.68	530.93	74	232.4	4300.8
5¾	18.06	25.967	27	84.82	572.55	75	235.6	4417.8
6	18.84	28.274	28	87.96	615.75	76	238.7	4536.4
6¼	19.63	30.679	29	91.10	660.52	77	241.9	4656.6
6½	20.42	33.183	30	94.24	706.86	78	245.0	4778.3
6¾	21.20	35.784	31	97.38	754.76	79	248.1	4901.6
7	21.99	38.484	32	100.5	804.24	80	251.3	5026.5
7¼	22.77	41.282	33	103.6	855.30	81	254.4	5153.0
7½	23.56	44.178	34	106.8	907.92	82	257.6	5281.0
7¾	24.34	47.173	35	109.9	962.11	83	260.7	5410.6
8	25.13	50.265	36	113.0	1017.8	84	263.8	5541.7
8¼	25.91	53.456	37	116.2	1075.2	85	267.0	5674.5
8½	26.70	56.745	38	119.3	1134.1	86	270.1	5808.8
8¾	27.48	60.132	39	122.5	1194.5	87	273.3	5944.6
9	28.27	63.617	40	125.6	1256.6	88	276.4	6082.1
9¼	29.05	67.200	41	128.8	1320.2	89	279.6	6221.1
9½	29.84	70.882	42	131.9	1385.4	90	282.7	6361.7
9¾	30.63	74.662	43	135.0	1452.2	91	285.8	6503.8
10	31.41	78.539	44	138.2	1520.5	92	289.0	6647.6
10¼	32.20	82.516	45	141.3	1590.4	93	292.1	6792.9
10½	32.98	86.590	46	144.5	1661.9	94	295.3	6936.7
10¾	33.77	90.762	47	147.6	1734.9	95	298.4	7088.2
11	34.55	95.033	48	150.7	1809.5	96	301.5	7238.2
11¼	35.34	99.402	49	153.9	1885.7	97	304.7	7389.8
11½	36.12	103.86	50	157.0	1963.5	98	307.8	7542.9
11¾	36.91	108.43	51	160.2	2042.8	99	311.4	7697.7
12	37.69	113.09	52	163.3	2123.7	100	314.1	7853.9
12¼	38.48	117.85						

Drawing Paper, Sizes of.

	Ins.		Ins.
Foolscap	17 by 13½	Imperial	30 by 22
Demy	20 „ 15½	Columbier	34½ „ 23½
Medium	22 „ 17½	Atlas	34 „ 26
Royal	24 „ 19	Double Elephant	40 „ 26¾
Super Royal	27 „ 19	Antiquarian	53 „ 31
Elephant	28 „ 23		

Earthwork.

Weight per Cubic Foot and Angle with Horizon at which the Material will stand.

	Degrees.	Lbs. per cubic foot.
Clay, drained	45	105
Rubble	45	100
Earth, compact	50	125
Earth, loose	30	95
Gravel	40	120
Shingle	39	105
Sand, dry	38	120
Chalk	—	146
Mud	—	105

Flat Bar Iron.

Weight of a Lineal Foot.

Width in Ins.	Thickness in Inches.											
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1/16	.0132	.0263	.0395	.0526	.0658	.0789	.0921	.1053	.1316	.1579	.1842	.2105
1/8	.0263	.0526	.0789	.1053	.1316	.1579	.1842	.2105	.2631	.3158	.3684	.4210
3/16	.0395	.0789	.1184	.1579	.1973	.2368	.2763	.3158	.3947	.4736	.5526	.6315
1/4	.0526	.1053	.1579	.2105	.2631	.3158	.3684	.4210	.5263	.6315	.7368	.8420
5/16	.0658	.1316	.1973	.2631	.3289	.3947	.4605	.5263	.6578	.7894	.9210	1.053
3/8	.0789	.1579	.2368	.3158	.3947	.4736	.5526	.6315	.7894	.9473	1.105	1.263
7/16	.0921	.1842	.2763	.3684	.4605	.5526	.6447	.7368	.9210	1.105	1.289	1.474
1/2	.1053	.2105	.3158	.4210	.5263	.6315	.7368	.8420	1.053	1.263	1.474	1.684
9/16	.1184	.2368	.3552	.4736	.5920	.7104	.8289	.9473	1.184	1.421	1.658	1.895
5/8	.1316	.2631	.3947	.5263	.6578	.7894	.9210	1.053	1.316	1.579	1.842	2.105
11/16	.1447	.2894	.4342	.5789	.7236	.8683	1.013	1.158	1.447	1.737	2.026	2.316
3/4	.1579	.3158	.4736	.6315	.7894	.9473	1.105	1.263	1.579	1.895	2.210	2.526
13/16	.1710	.3421	.5131	.6841	.8552	1.026	1.197	1.368	1.710	2.052	2.394	2.737
7/8	.1842	.3684	.5526	.7368	.9210	1.105	1.289	1.474	1.842	2.210	2.579	2.947
15/16	.1973	.3947	.5920	.7894	.9867	1.184	1.381	1.579	1.973	2.368	2.763	3.158
1	.210	.421	.632	.842	1.053	1.263	1.474	1.684	2.105	2.526	2.947	3.368
1 1/8	.237	.474	.710	.947	1.184	1.421	1.658	1.895	2.368	2.842	3.315	3.789
1 1/4	.263	.526	.789	1.053	1.316	1.579	1.842	2.105	2.631	3.158	3.684	4.210
1 3/8	.289	.579	.868	1.158	1.447	1.737	2.026	2.316	2.894	3.473	4.052	4.631
1 1/2	.316	.632	.947	1.263	1.579	1.895	2.210	2.526	3.158	3.789	4.421	5.052
1 5/8	.342	.684	1.026	1.368	1.710	2.052	2.394	2.737	3.421	4.105	4.789	5.473
1 3/4	.368	.737	1.105	1.474	1.842	2.210	2.579	2.947	3.684	4.421	5.157	5.894
1 7/8	.395	.789	1.184	1.579	1.973	2.368	2.763	3.158	3.947	4.736	5.526	6.315
2	.421	.842	1.263	1.684	2.105	2.526	2.947	3.368	4.210	5.052	5.894	6.736
2 1/8	.447	.895	1.342	1.789	2.237	2.684	3.131	3.579	4.473	5.368	6.262	7.157
2 1/4	.474	.947	1.421	1.895	2.368	2.842	3.315	3.789	4.736	5.684	6.831	7.578
2 3/8	.500	1.000	1.500	2.000	2.500	3.000	3.500	4.000	4.999	5.999	6.999	7.999
2 1/2	.526	1.053	1.579	2.105	2.631	3.158	3.684	4.210	5.263	6.315	7.368	8.420
2 5/8	.553	1.105	1.658	2.210	2.763	3.315	3.868	4.421	5.526	6.631	7.736	8.841
2 3/4	.579	1.158	1.737	2.316	2.894	3.473	4.052	4.631	5.789	6.947	8.104	9.262
2 7/8	.605	1.210	1.816	2.421	3.026	3.631	4.236	4.842	6.052	7.262	8.473	9.683
3	.632	1.263	1.895	2.526	3.158	3.789	4.421	5.052	6.315	7.578	8.841	10.104
3 1/4	.684	1.368	2.052	2.737	3.421	4.105	4.789	5.473	6.841	8.210	9.578	10.946
3 1/2	.737	1 474	2.210	2.947	3.684	4.421	5.157	5.894	7.368	8.841	10.315	11.788
3 3/4	.789	1.579	2.368	3.158	3.947	4.736	5.526	6.315	7.894	9.473	11.051	12.630
4	.842	1.684	2.526	3.368	4.210	5.052	5.894	6.736	8.420	10.104	11.788	13.472
4 1/4	.895	1.789	2.684	3.579	4.473	5.368	6.262	7.157	8.946	10.736	12.525	14.314
4 1/2	.947	1.895	2.842	3.789	4.736	5.684	6.631	7.578	9.473	11.367	13.262	15.156
4 3/4	1.000	2.000	3.000	4.000	4.999	5.999	6.999	7.999	9.999	11.999	13.998	15.998
5	1.053	2.105	3.158	4.210	5.263	6.315	7.368	8.420	10.525	12.630	14.735	16.840
5 1/4	1.105	2.210	3.315	4.421	5.526	6.631	7.736	8.841	11.051	13.262	15.472	17.682
5 1/2	1.158	2.316	3.473	4.631	5.789	6.947	8.104	9.262	11.578	13.893	16.209	18.524
5 3/4	1.210	2.421	3.631	4.842	6.052	7.262	8.473	9.683	12.104	14.525	16.946	19.366
6	1.263	2.526	3.789	5.052	6.315	7.578	8.841	10.104	12.630	15.156	17.682	20.208

Girders (Timber), Strength of.

Breadth in inches multiplied by the depth in inches squared, divided by the length of the unsupported span in feet; multiply the quotient by 3 for Riga fir, by 5 for red pine, by 5 for English oak. The answer is in cwts.

Girders (Rolled Wrought Iron).

Multiply the area of the bottom flange, including the lower quarter of the web (treat it as tee iron), by six times the depth, divide by the unsupported length in feet; gives breaking weight in tons in the centre. Safe load, one-fourth to one-fifth.

Proportionate Load.	Tons.
Girder embedded at both ends, load concentrated in the centre, equals	x
Girder supported at both ends, load distributed, equals . .	x
Girder embedded at each end, load distributed, equals . .	$\frac{3x}{2}$
Girder supported at both ends, load concentrated in the centre, equals	$\frac{x}{2}$
Girder supported at one end only, load distributed, equals . .	$\frac{x}{4}$
Girder supported at one end only, load concentrated at further end	$\frac{x}{8}$

Rolled Wrought-Iron Girders.

SAFE PERMANENT DISTRIBUTED LOAD IN CWTS.

Dimensions in Inches.	Weight per Foot in Lbs.	Span.							
		6 Ft.	8 Ft.	10 Ft.	12 Ft.	16 Ft.	20 Ft.	24 Ft.	28 Ft.
$4 \times 1\frac{3}{4} \times 1\frac{3}{4}$	8	45	34	27	22	17	13	11	9
$5 \times 2 \times 2$	10	74	50	40	35	25	20	17	15
$4\frac{5}{8} \times 3\frac{1}{4} \times 3$	14	90	66	53	44	34	27	22	17
$7 \times 2\frac{1}{8} \times 2\frac{1}{8}$	18	180	135	118	94	72	56	44	34

Hydraulic Memoranda.

1 gal. (Imperial) = 277.27 cub. in. = 10 lbs. = 1.2 gal. (American) = 4.537 litres.

1 gal. (American) = 231 cub. in. = 8.33 lbs. = .83 gal. (Imperial) = 3.8 litres.

1 cub. ft. fresh water = 62.425 lbs. = .557 cwt. = 6.24 gals.

1 cub. ft. salt water = 64.11 lbs. = 6.25 gals.

1 lb. fresh water = 27.72 cub. in. = .1 gal. (Imperial).

1 ton fresh water = 36 cub. ft.

Pressure in pounds per square inch = vertical head multiplied by .433.

Pressure in pounds per square inch × 2.31 = vertical head in feet.

Pounds of water in a pipe . = diameter of pipe in inches squared multiplied by the length in yards.

Efflux of water under pressure in tons per hour per square inch = head in feet multiplied by 20; take the square root of the product.

The friction of water in pipes varies as the square of the velocity.

Assuming an efficiency of 75 per cent. in the motor,

The Horse-power . . . = cubic feet per minute multiplied by fall in feet divided by 706.

Cubic feet required per H.P. . = H.P. multiplied by 706 divided by the fall in feet.

Fall required for H.P. . . = H.P. multiplied by 706 divided by number of cubic feet per minute.

Iron, Round and Square Bar.

WEIGHT PER FOOT.

Inches Diam.	Round.	Square.	Inches Diam.	Round.	Square.
	Lbs.	Lbs.		Lbs.	Lbs.
$\frac{1}{4}$	0.164	0.2	$2\frac{3}{4}$	19.84	25.26
$\frac{3}{8}$	0.36	0.47	$2\frac{7}{8}$	21.7	27.6
$\frac{1}{2}$	0.65	0.833	3	23.6	30.07
$\frac{5}{8}$	1.02	1.3	$3\frac{1}{4}$	27.87	35.25
$\frac{3}{4}$	1.47	1.87	$3\frac{1}{2}$	32.1	41.0
$\frac{7}{8}$	2.01	2.55	$3\frac{3}{4}$	36.9	47.0
1	2.62	3.34	4	42.0	53.4
$1\frac{1}{8}$	3.32	4.22	$4\frac{1}{4}$	47.4	60.32
$1\frac{1}{4}$	4.09	5.25	$4\frac{1}{2}$	53.1	67.06
$1\frac{3}{8}$	4.96	6.35	$4\frac{3}{4}$	59.2	75.03
$1\frac{1}{2}$	5.9	7.51	5	65.5	83.5
$1\frac{5}{8}$	6.9	8.82	$5\frac{1}{4}$	72.3	92.5
$1\frac{3}{4}$	8.03	10.29	$5\frac{1}{2}$	79.4	101.0
$1\frac{7}{8}$	9.22	11.74	$5\frac{3}{4}$	86.7	110.5
2	10.5	13.36	6	94.5	120.2
$2\frac{1}{8}$	11.84	15.08	$6\frac{1}{2}$	111.0	142.0
$2\frac{1}{4}$	13.27	16.91	7	128.0	164.0
$2\frac{3}{8}$	14.79	18.85	$7\frac{1}{2}$	149.0	188.0
$2\frac{1}{2}$	16.4	20.8	8	168.0	214.0
$2\frac{5}{8}$	18.07	23.1	9	212.0	272.0

The weight of bar iron in pounds per foot of length equals—

1. The sectional area in inches multiplied by 3.34.
2. The sectional area in eighths of an inch multiplied by .052.

Sheet iron weighs 5 lbs. per square foot for each eighth of an inch.

$\frac{1}{16}$ in. thick = $2\frac{1}{2}$ lbs. per foot.
$\frac{1}{8}$ " = 5 " "
$\frac{1}{4}$ " = 10 " "
$\frac{1}{2}$ " = 20 " "

Metals.

	Specific Gravity.	Weight per Cub. Ft.	Weight per Cub. In.	Tensile Strength per Sq. In.	Melting Point.
		Lbs.	Lbs.	Tons.	Fahr.
Aluminium, cast	2.67	166.6	.096	...	...
Antimony, cast	6.72	418.17	.242	0.47	810°
Bismuth, cast	9.82	613.0	.3547	1.45	495
Copper, cast	8.607	535.6	.31	8.4	1950
,, bars	8.85	549.5	.318	17.0	...
Gold	19.361	1208.5	.699	9.1	2100
Iron, cast	7.25	449.0	.26	7.3	2786
,, wrought	7.78	485.6	.28	22.0	...
Lead	11.36	708.5	.41	0.8	612
Mercury	13.59	846.72	.49	...	...
Platinum	21.531	1343.9	.775	...	3080
Silver	10.474	635.8	.37	...	1873
Steel	8.0	499.0	.288	50.0	2255
Tin	7.29	455.0	.262	2.0	442
Zinc	7.0	437.0	.252	3.3	736

Materials, Various.

Brickwork in Mortar	22½ cub. ft.	= 1 ton	1 cub. ft. = 100 lbs.
Charcoal	123 ,,	= ,,	,, = 18 ,,
Clay, solid	17 ,,	= ,,	,, = 132 ,,
Concrete	18½ ,,	= ,,	,, = 120 ,,
Coal, bituminous, loose	44 ,,	= ,,	,, = 51 ,,
Coal, anthracite	42 ,,	= ,,	,, = 52.5 ,,
Earth, solid	18 ,,	= ,,	,, = 120 ,,
Gravel	18 ,,	= ,,	,, = 120 ,,
Granite	13.5 ,,	= ,,	,, = 166 ,,
Masonry, rubble	16 ,,	= ,,	,, = 140 ,,
Sand, pit	22½ ,,	= ,,	,, = 100 ,,
Quartz, in position	13 ,,	= ,,	
Quartz, broken	20 ,,	= ,,	
Oil, lubricating	1 ,,	= 6.23 gals. 58 lbs.	
Oil, Petroleum	1 ton	= 275 gals.	
Tallow	1 cub. ft. = 59 lbs.		
Air at sea level, at 62° Fahr.	1 cub. ft. = .076 lb		

Mensuration.

Circle—

Diameter multiplied by 3.14159 equals the circumference.
Diameter multiplied by .886226 equals side of equal square.
Diameter multiplied by .7071 equals side of inscribed square.
Diameter squared and multiplied by .7854 equals the area.
Length of arc multiplied by half the radius equals area of sector.

The area of a—

Circle . . .	= Diameter squared multiplied by .7854.
Parabola . . .	= Two-thirds of the base multiplied by height.
Ellipse . . .	= Transverse and conjugate axes multiplied together and multiplied by .7854.
Triangle . . .	= Half the product of the base multiplied by the vertical height.
Equilateral triangle .	= The square of one side multiplied by .433.
Square or Parallelogram	= The product of two adjacent sides.
Sphere . . .	= Diameter squared and multiplied by 3.1416.

The cubic contents of a—

Cube . . .	= Height, length, and breadth multiplied together.
Sphere . . .	= Diameter cubed multiplied by .5236.
Cylinder or Prism .	= Area of base multiplied by length.
Cone . . .	= Area of base multiplied by one-third of the height.
Wedge . . .	= Area of base multiplied by half the length.

Names, Common and Chemical.

Common.	Chemical.
Aqua fortis	Nitric Acid.
Cream of Tartar	Bitartrate of Potassium.
Chalk	Carbonate of Calcium.
Caustic Potash	Hydrate of Potassium.
Corrosive Sublimate	Bi-chloride of Mercury.
Epsom Salts	Sulphate of Magnesia.
Galena	Sulphide of Lead.
Glauber's Salts	Sulphate of Sodium.
Iron Pyrites	Bi-sulphide of Iron.
Jewellers' Putty	Oxide of Tin.
Lime	Oxide of Calcium.
Lunar Caustic	Nitrate of Silver.
Salt	Chloride of Sodium.
Saltpetre	Nitrate of Potash.
Potash	Oxide of Potassium.
Red Lead	Oxide of Lead.
Rust	Oxide of Iron.
Sal Ammoniac	Chloride of Ammonium.
Slaked Lime	Calcium Hydrate.
Soda	Oxide of Sodium.
Spirits of Salts	Hydrochloric Acid.
Sugar of Lead	Acetate of Lead.
Vermilion	Sulphide of Mercury.
Vitriol, blue	Sulphate of Copper.
Vitriol, green	Sulphate of Iron.
Vitriol, white	Sulphate of Zinc.
Vitriol, Oil of	Sulphuric Acid.

Pipes.

PRESSURE REQUIRED IN POUNDS PER SQUARE INCH TO DELIVER VARIOUS QUANTITIES OF WATER THROUGH 100 FEET OF PIPE.

Bore of Pipe.	Gallons.								
	4	8	12	16	20	24	30	40	60
Inches.									
1	.84	3.16	7.0	12.3	19.0	27.0	39.0	...	...
1½	.12	0.5	1.0	1.6	2.6	3.25	5.25	9.5	20.0
2	...	0.12	0.27	0.42	0.67	0.9	1.35	2.3	4.8
2½	...	...	...	0.12	0.21	0.3	0.5	0.78	1.4
3	...	...	...	...	...	...	0.14	0.35	0.7

Bore of Pipe.	Gallons.							
	80	100	125	150	175	200	250	300
3	1.1	1.2	2.85	4.0	5.3	7.5	...	...
4	0.3	0.5	0.7	1.0	1.25	1.8	2.6	3.75
6	...	...	0.1	0.15	0.2	0.25	0.37	0.52

Pumps.

Short rule for the displacement of pumps in gallons per foot of stroke—Diameter in inches squared and divided by 30.

Steel.

The weight of octagonal steel in pounds per foot equals the diameter in eighths of an inch squared, and multiplied by 11, and divided by 250.

WEIGHT OF BAR STEEL IN POUNDS PER FOOT.

Diameter.	Round.	Octagonal.	Square.
Inches.	Lbs.	Lbs.	Lbs.
$\frac{5}{8}$	1.044	1.101	1.329
$\frac{3}{4}$	1.503	1.586	1.914
$\frac{7}{8}$	2.046	2.158	2.605
1	2.673	2.819	3.403
$1\frac{1}{8}$	3.382	3.568	4.307
$1\frac{1}{4}$	4.176	4.405	5.317
$1\frac{3}{8}$	5.053	5.33	6.433
$1\frac{1}{2}$	6.013	6.343	7.656
$1\frac{5}{8}$	7.057	7.444	8.985
$1\frac{3}{4}$	8.185	8.633	10.421
$1\frac{7}{8}$	9.396	9.92	11.963
2	10.69	11.276	13.611
$2\frac{1}{4}$	13.53	14.256	17.227
$2\frac{1}{2}$	16.703	17.618	21.267

Solders.

Solders for	Component Parts.							
	Tin.	Copper.	Brass.	Lead.	Antimony.	Bismuth.	Pewter.	Zinc.
Lead . . .	1	...	...	$1\frac{1}{2}$	...	...	...	...
Tin . . .	1	...	...	...	...	1	4	...
,, . . .	1	...	...	2	...	...	...	...
Pewter . .	2	...	...	1	...	2	...	...
,, . . .	2	...	...	1	...	...	...	...
Brass . . .	...	...	2	...	...	...	...	1
Solder, soft . .	2	...	...	1	...	...	...	...
,, hard .	...	2	...	...	...	...	...	1
Brazing, soft .	2	...	...	...	1	...	...	...
,, hard .	...	1	...	...	...	...	...	1
,, very hard	...	3	...	...	...	...	...	1

Solders, Special.

Silver Solder.—Three parts silver to one of brass.

Silver Solder, Hard.—Four parts silver, one part copper.

Silver Solder for Brazing Steel.—Nineteen parts silver, one part copper, two of brass.

Screw Threads.

WHITWORTH STANDARD SCREW THREAD—ANGLE 55 DEGREES, DEPTH EQUAL TO THE PITCH, ONE-SIXTH ROUNDED OFF THE TOP AND BOTTOM.

Diameter of Bolt.	Safe Load in Lbs.	Threads per Inch.	Diameter of Bolt.	Safe Load in Lbs.	Threads per Inch.
$\frac{3}{16}$	80	24	$\frac{7}{8}$	3,100	9
$\frac{1}{4}$	170	20	1	4,050	8
$\frac{5}{16}$	300	18	$1\frac{1}{8}$	5,100	7
$\frac{3}{8}$	450	16	$1\frac{1}{4}$	6,600	7
$\frac{7}{16}$	620	14	$1\frac{3}{8}$	9,550	6
$\frac{1}{2}$	810	12	$1\frac{1}{2}$	...	6
$\frac{5}{8}$	1,450	11	$1\frac{3}{4}$	...	5
$\frac{3}{4}$	2,200	10	2	...	$4\frac{1}{2}$

Timber.

To hasten the seasoning of timber, allow the felled tree to lie without trimming any of the branches; the leaves draw a large proportion of the sap from the trunk. Trim the tree when the leaves have withered.

STRENGTH AND WEIGHT OF TIMBER.

	Weight in lbs. per cub. ft.	Tensile Strength in lbs. per sq. in.	Crushing Weight in lbs. per sq. in.
Acacia	46	16,000	...
Ash	45	13,000	9,000
Beech	43	15,000	8,500
Cedar	47	5,000	5,700
Chestnut	38	12,000	...
Deal	43	12,000	5,850
Elm	40	13,000	10,300
Fir	32	10,100	6,500
Lignum vitæ	83	11,800	10,000
Mahogany	50	21,000	8,000
Oak	53	10,000	6,400
Pine, red	40	12,000	5,400
Teak	46	8,000	12,000

Water.

THEORETICAL DISCHARGE UNDER PRESSURE.

The velocity in feet per second is eight times the square root of the head in feet.

The quantity discharged in gallons per minute is the square root of the height, multiplied by the diameter of the opening squared, multiplied by 16.3.

The rainfall in inches multiplied by 3,630 equals millions of gallons per acre.

Wheels for Screw-Cutting.

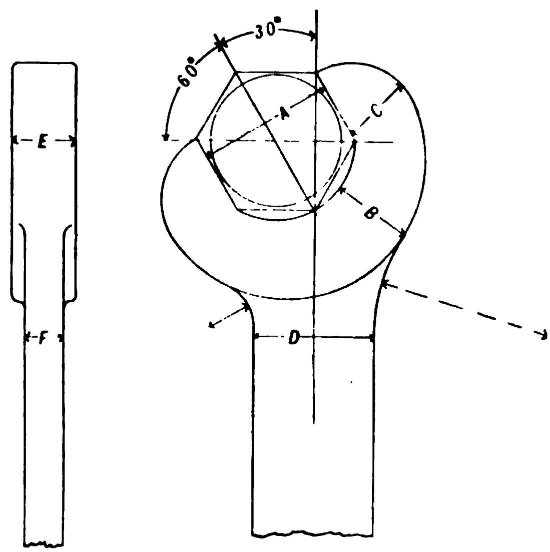
TABLE OF CHANGE WHEELS FOR WHITWORTH'S STANDARD THREADS.

Diameter of Screw.	No. of Threads per Inch.	Main Screw of 2 per In.				Main Screw of 3 per In.				Main Screw of 4 per In.			
		M.	S.W.	S.P.	S.	M.	S.W.	S.P.	S.	M.	S.W.	S.P.	S.
Inches.													
¼	20	20	90	45	100	30	90	45	100	20	50	45	90
$\frac{5}{16}$	18	20	90	50	100	30	80	40	90	20	...	...	90
⅜	16	20	80	50	100	30	80	45	90	20	...	...	80
$\frac{7}{16}$	14	20	70	50	100	30	70	45	90	20	...	...	70
½	12	20	60	50	100	30	60	45	90	20	...	...	60
⅝	11	20	55	50	100	30	55	45	90	20	...	...	55
¾	10	40	90	45	100	30	50	45	90	20	...	...	50
⅞	9	40	90	50	100	30	...	...	90	20	...	...	45
1	8	40	80	50	100	30	...	...	80	20	...	...	40
1⅛ and 1¼	7	40	70	50	100	30	...	...	70	20	...	...	35
1⅜ ,, 1½	6	40	60	50	100	30	...	...	60	20	...	...	30
1⅝ ,, 1¾	5	40	...	...	100	30	...	...	50	20	..	...	25
1⅞ ,, 2	4½	40	...	...	90	30	...	...	45	40	...	...	45
2¼ ,, 2½	4	40	...	...	80	30	...	...	40	40	...	...	40
2¾ ,, 3	3½	40	...	...	70	30	...	...	35	40	...	...	35

M. denotes the wheel on mandrel; S.W. the stud wheel; S.P. the stud pinion; and S. the screw wheel. Where no wheels are shown, any convenient one will answer to gear M. and S. together.

PROPORTION OF PARTS.

SPANNERS—ROD BEARINGS—ROD ENDS—LINK ENDS—FORKED ENDS—CRANKS—LEVERS.

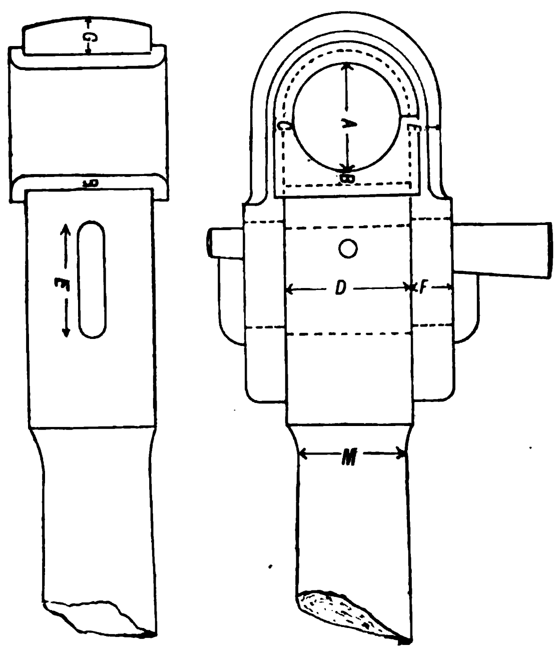


Spanners.

FIG. 90.

A = width of nut.	D = A × .825.
B = A × .47.	E = A × .4.
C = A × .44.	F = A × .225.

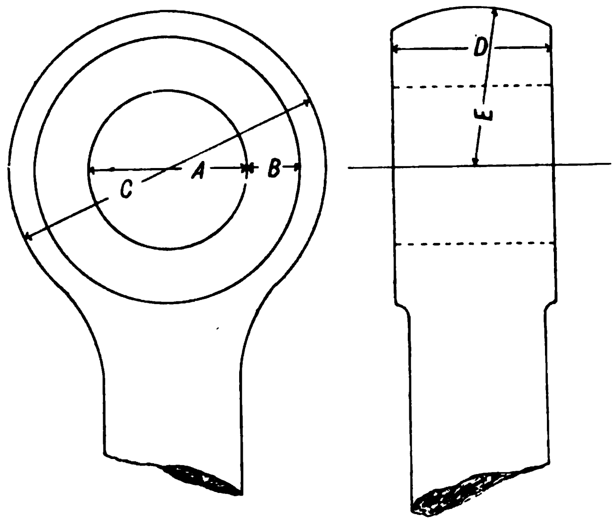
Length of handle A × 9.



Rod Bearings.

FIG. 91.

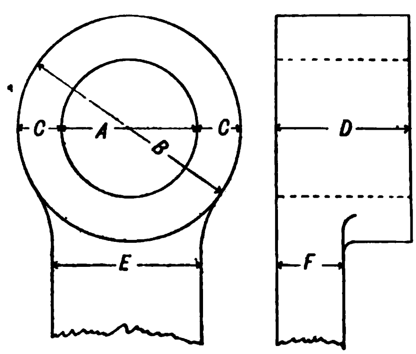
A = diameter of bearing.
B = A × .15.
C = $\frac{1}{8}$ less than B.
D = A + 2C.
E = A × .4.
F = A × .43.
G = E.
L = A.
M = A.



Rod Ends.

FIG. 92.

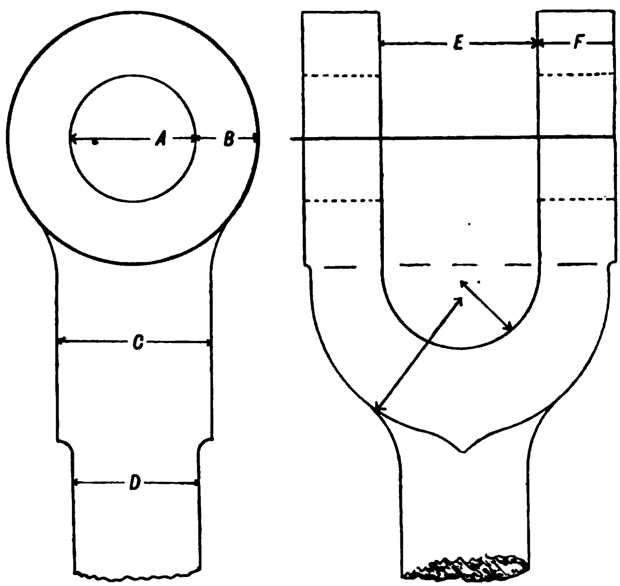
A = diameter of pin.
B = one-third of A.
C = A × 2.
D = A.
E = A.



Link Ends.

FIG. 93.

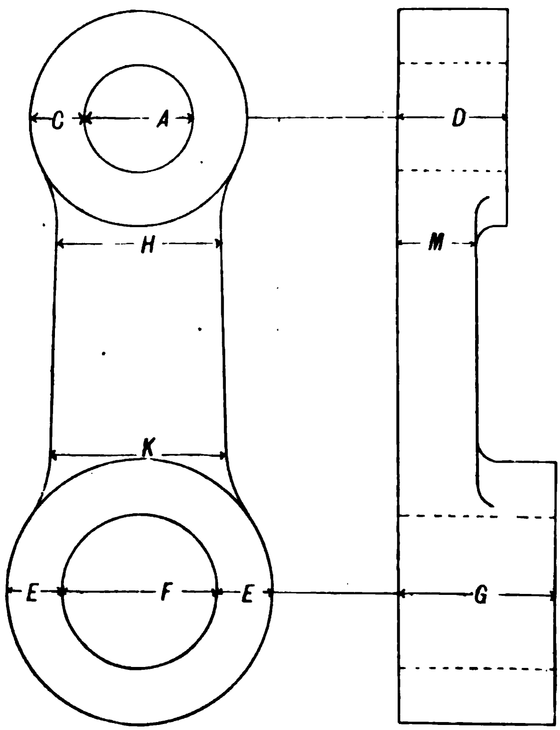
A = diameter of pin.
B = two-thirds of 2A
C = one-third of A.
D = A.
E = two-thirds of B.
F = half A.



Forked Ends.

FIG. 94.

A = diameter of pin.
B = half A.
C = A + $\frac{1}{8}$.
D = A.
E = A.
F = half A.



Cranks. Levers.

FIG. 95.

A = diameter of pin.	F = shaft.
C = half A.	G = F.
D = A.	H = one and a half A.
E = one-third of F.	K = F and E added together.

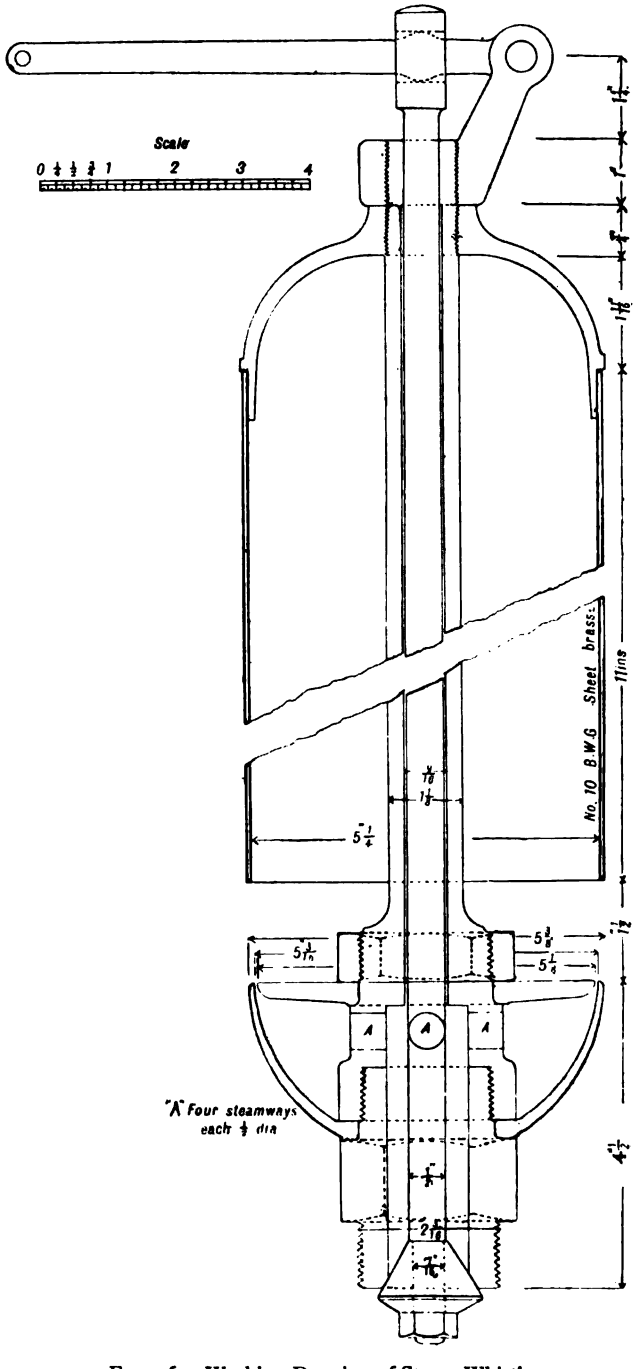


FIG. 96.—Working Drawing of Steam Whistle.

INDEX.

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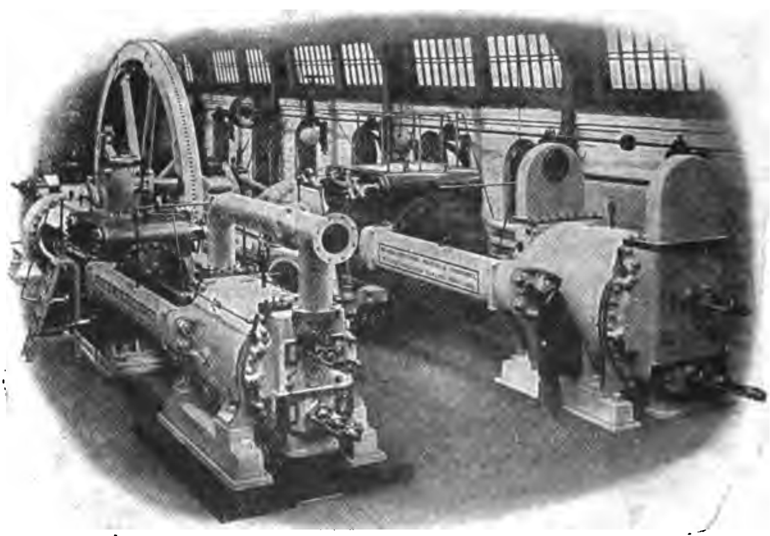

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